# 5. External Components

## 5.1 INTRODUCTION

External components of the air cleaning system include fans, ductwork, dampers, housings, stacks, instruments, and other items of the system concerned with the movement, control, conveying, and monitoring of airflow and/or gas flow, as opposed to the internal components discussed in Chap. 3. In most cases, external components constitute a portion of the pressure boundary or are external to the pressure boundary of the system.

## 5.2 DUCTWORK

### 5.2.1 Functional Design

The sizing and layout of ductwork to provide desired air distribution, ventilation rates, transport velocities, and other functional requirements of the ventilation system are covered by ASHRAE handbooks,[1] ACGIH's *Industrial Ventilation*,[2] and ANSI Z9.2.[3] The purpose of this section is to review the physical aspects of the duct system in relation to nuclear air cleaning. The least expensive first-cost duct layout may not be the most economical when total annual cost of operating the system is considered. Short-radius elbows and other shortcuts in ductwork may seriously increase system resistance, requiring, for instance, the use of a larger fan and/or fan motor and resulting in higher operating costs, or conversely, making it impossible for the system, as installed, to operate at the desired level of performance. The physical layout of ductwork in a building is often compromised to conform to the confines of a building structure or design. This may be unavoidable when installing new ducts in an existing building. In new construction, consideration should be given to providing adequate space and optimizing configuration for duct layout in the earliest phases of building layout long before the building design has been finalized. Easy access to filter housings, fans, dampers, and other components is vital to maintainability and testability, and therefore to reliability of the system. The allowance of adequate space for well-designed elbows, size transitions, and fan inlets and outlets is vital to least-cost operation.

### 5.2.2 Mechanical Design

Duct cost is influenced by the size and quantities of ductwork, materials of construction, coatings used for protection against corrosion, construction methods (seams, joints, etc.), airtightness requirements, the sequence of erection (including a consideration of space limitations, posterection cleaning requirements, etc.), and the number and type of field connections and supports (hangers, anchors, etc.) required. Consideration should be given to future modification, dismantling, and disposal of contaminated ductwork, particularly in the design of systems for laboratories, experimental facilities, and other operations where change of the ductwork can be expected. The provision for adding on or changing ductwork is a consideration often overlooked in initial design.

Where space permits, round duct is generally preferred to rectangular duct because it is stronger (particularly under negative or collapsing pressure), is more economical for high pressure construction often required for nuclear applications, provides more uniform airflow, and is easier to join and seal than rectangular duct. The principal disadvantages of round duct are that it makes less efficient use of building space and that it is sometimes difficult to make satisfactory branch connections. Any duct system that carries radioactive material, or that could carry radioactive material under upset conditions, should be considered as a safety-related system. The level of radioactivity will largely determine the quality of duct construction required. Although it is sometimes assumed that all leakage in negative pressure ductwork will be inleakage, this is not necessarily true. In the event of fire or explosion in a contained space (room, enclosure, hot cell, glove box, or containment structure) served by the system, ductwork can become positively pressured (with resultant outleakage). Outleakage can also be caused by a rapidly closing damper or by dynamic effects (in a poorly laid out system) under normal operating conditions. Under system shutdown conditions or during maintenance, the possibility of outleakage from normally negative-pressure ductwork also exists. The engineer must consider these possibilities in the design and specification of permissible leak rates for negative-pressure portions of safety-related systems. In addition, ducts that normally carry clean air can sometimes become contaminated. Ducts must be sized for the transport velocities needed to convey, without settling, all particulate contaminants. Recommended transport velocities are given in Sect. 5 of *Industrial Ventilation*.[2] Ducts for most nuclear exhaust and postaccident air cleanup systems should be sized for a minimum duct velocity of 2500 fpm.

Tables 5.1 through 5.4 list suggested sheet metal gages and reinforcement for negative-pressure ducts operating at pressures below 2 in.wg negative. Suggested gages and reinforcement for positive-pressure ducts are given in the SMACNA standards.[4]

**Table 5.1. Recommended sheet-metal thicknesses for round duct under negative pressure**
Factor of safety = 3 over code based on ultimate strength for ducts with diameters up to 24 in. and 5 over code for ducts with diameters over 24 in., based on paragraph UG-28 in Sect. VII of the *ASME Boiler and Pressure Vessel Code*

| Negative pressure in duct | Reinforcement spacing (in.) | Sheet-metal thickness (U.S. gage no.)[a] for duct diameter of – | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 4 in. | 8 in. | 12 in. | 16 in. | 20 in. | 24 in. | 36 in. | 48 in. | 60 in. |
| 4 in.wg | ∞[b] | 24 | 24 | 20 | 18 | 16 | 14 | 10 | 8 | 4 |
| | 96 | 24 | 24 | 24 | 22 | 20 | 18 | 16 | 14 | 14 |
| | 48 | 24 | 24 | 24 | 24 | 24 | 22 | 20 | 18 | 16 |
| | 24 | 24 | 24 | 24 | 24 | 24 | 24 | 22 | 20 | 18 |
| 8 in.wg | ∞ | 24 | 22 | 18 | 16 | 14 | 12 | 8 | 4 | |
| | 96 | 24 | 22 | 22 | 18 | 18 | 18 | 14 | 12 | 12 |
| | 48 | 24 | 24 | 24 | 22 | 20 | 20 | 16 | 14 | 14 |
| | 24 | 24 | 24 | 24 | 24 | 22 | 22 | 18 | 16 | 16 |
| 12 in.wg | ∞ | 24 | 20 | 16 | 14 | 12 | 12 | 6 | 2 | |
| | 96 | 24 | 22 | 18 | 18 | 16 | 16 | 12 | 11 | 11 |
| | 48 | 24 | 22 | 22 | 20 | 18 | 18 | 14 | 14 | 12 |
| | 24 | 24 | 24 | 24 | 22 | 22 | 22 | 16 | 16 | 16 |
| 20 in.wg | ∞ | 24 | 18 | 14 | 12 | 11 | 8 | 4 | | |
| | 96 | 24 | 20 | 16 | 16 | 14 | 14 | 11 | 11 | 8 |
| | 48 | 24 | 22 | 20 | 18 | 16 | 16 | 14 | 12 | 11 |
| | 24 | 24 | 24 | 22 | 20 | 18 | 18 | 16 | 14 | 12 |
| | 12 | | | | | | | | 20 | 16 |
| 1 psi | ∞ | 20 | 14 | 12 | 10 | 8 | 6 | | | |
| | 96 | 24 | 18 | 16 | 14 | 12 | 12 | 10 | 8 | 6 |
| | 48 | 24 | 20 | 18 | 18 | 16 | 16 | 12 | 11 | 11 |
| | 24 | 24 | 24 | 22 | 20 | 18 | 18 | 14 | 12 | 12 |
| | 12 | | | | | | | | 16 | 14 |
| 2 psi | ∞ | 18 | 12 | 11 | 8 | 4 | 2 | | | |
| | 96 | 22 | 16 | 14 | 12 | 12 | 11 | 6 | 6 | 4 |
| | 48 | 24 | 18 | 16 | 14 | 14 | 12 | 10 | 8 | 6 |
| | 24 | 24 | 20 | 18 | 18 | 16 | 16 | 11 | 11 | 11 |
| | 12 | | | | | | | 14 | 12 | 12 |

[a]Minimum sheet-metal thickness for shop-welded duct is No. 18 U.S. gage. Minimum sheet-metal thickness for field-welded duct is No. 16 U.S. gage.

[b]Where ∞ is shown, no reinforcement is required.

Table 5.2. Recommended ASTM A36 angle reinforcement for round duct under negative pressure

| Negative pressure in duct | Angle size[a] for duct diameter of – | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4 in. | 8 in. | 12 in. | 16 in. | 20 in. | 24 in. | 36 in. | 48 in. | 60 in. |
| 4 in.wg | A | A | A | B | B | B | B | C | C |
| 8 in.wg | A | A | A | B | B | B | B | C | C |
| 12 in.wg | A | A | A | B | B | B | B | C | C |
| 20 in.wg | A | A | A | B | B | B | B | C | C |
| 1 psi | A | A | A | B | B | C | C | C | C |
| 2 psi | A | A | A | B | B | C | C | D | D |
| 4 psi | A | A | A | B | B | C | C | D | D |

[a]Symbol for angle size (in.): A = $1 \times 1 \times {}^{3}/_{16}$; B = $1^{1}/_{2} \times 1^{1}/_{2} \times {}^{1}/_{4}$; C = $2 \times 2 \times {}^{1}/_{4}$; D = $2^{1}/_{2} \times 2^{1}/_{2} \times {}^{1}/_{4}$.

*Source:* Based on R. J. Roark, *Formulas for Stress and Strain*, 4th ed., McGraw-Hill, 1965, Formula 12, Table XV.

Table 5.3. Recommended sheet-metal thicknesses for rectangular welded duct under negative pressure

| Negative pressure in duct (in.wg) | Reinforcement spacing (in.) | Sheet-metal thickness[a] (U.S. gage No.)[b] for longest side of length – | | | | |
|---|---|---|---|---|---|---|
| | | 12 in. | 24 in. | 36 in. | 48 in. | 60 in. |
| 4 | 48 | 18 | 18 | 16 | 14 | |
| 4 | 24 | 18 | 18 | 18 | 16 | 16 |
| 4 | 12 | 18 | 18 | 18 | 18 | 16 |
| 8 | 48 | 18 | 14 | 12 | 12 | |
| 8 | 24 | 18 | 16 | 16 | 14 | 14 |
| 8 | 12 | 18 | 18 | 18 | 18 | 18 |
| 12 | 48 | 18 | 12 | 8 | 11 | |
| 12 | 24 | 18 | 16 | 12 | 12 | 12 |
| 12 | 12 | 18 | 18 | 18 | 18 | 18 |
| 20 | 48 | 14 | 11 | 6 | 6 | |
| 20 | 24 | 14 | 14 | 11 | 11 | 11 |
| 20 | 12 | 18 | 14 | 14 | 14 | 14 |
| 1 psi | 48 | 12 | 10 | | | |
| | 24 | 16 | 12 | 11 | 10 | |
| | 12 | 18 | 14 | 12 | 11 | |
| 2 psi | 48 | 12 | 10 | | | |
| | 24 | 14 | 11 | 10 | 8 | |
| | 12 | 16 | 12 | 11 | 10 | |

[a]For maximum deflection of ${}^{1}/_{16}$ in./ft in the long dimension.
[b]Minimum sheet-metal thickness for field-welded duct is No. 16 U.S. gage.
*Source:* Based on R. J. Roark, flat plate formula for edges held but not fixed, *Formulas for Stress and Strain*, 4th ed., McGraw-Hill, 1965, p. 246.

Table 5.4. Recommended ASTM A36 angle reinforcement for rectangular ducts under negative pressure

Based on uniformly loaded beam with 50% simple support, 50% fixed ends, and deflection of $^1/_8$ in./ft

| Negative pressure in duct (in.wg) | Angle size[a] for ducts with maximum panel size of – | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 12 in. by – | | | | | 24 in. by – | | | | 48 in. by – | | |
| | 12 in. | 24 in. | 36 in. | 48 in. | 60 in. | 24 in. | 36 in. | 48 in. | 60 in. | 36 in. | 48 in. | 60 in. |
| 4 | E | E | E | F | F | E | G | G | G | H | H | H |
| 8 | E | E | E | F | F | E | G | G | G | H | H | H |
| 12 | E | E | E | F | F | E | G | G | G | H | H | H |
| 20 | E | F | H | H | | G | H | J | | | | |
| 1 psi | F | G | H | J | | H | J | K | | | | |
| 2 psi | G | H | J | L | | J | K | L | | | | |

[a]Symbol for angle size (in.): E = $1 \times 1 \times {}^3/_{16}$; F = $1^1/_4 \times 1^1/_4 \times {}^3/_{16}$; G = $1^1/_2 \times 1^1/_2 \times {}^3/_{16}$; H = $2 \times 2 \times {}^3/_{16}$; J = $2^1/_2 \times 2^1/_2 \times {}^1/_4$; K = $3 \times 2^1/_2 \times {}^1/_4$; L = $4 \times 3 \times {}^3/_8$.

For ducts to be field-fabricated by welding, a minimum of No. 18 U.S. gage, and preferably No. 16 U.S. gage, sheet metal is recommended because of the difficulty of making reliable field welds in thinner material. Section 5.10 of ANSI N509 recognizes several levels or grades of duct construction but does not define them (in terms of specific requirements) or distinguish clearly between them.[5] Because a nuclear facility may contain spaces of widely differing potential hazard level (see discussion of zoning, Sect. 2.2.1), the type of duct construction required may vary from one part of the plant to another. Questions that must be answered to establish the type of duct construction needed for a particular application include

1. Is the system safety-related?
2. If safety-related, is the level of radiation that exists in the duct, or that could exist in the duct in the event of a system upset, low? Intermediate? High?
3. Must the air cleaning system remain operable in the event of a system upset (power outage, accident, malfunction) or can it be shut down?
4. Where will the ductwork be located relative to (1) the contained space served by the system and (2) occupied spaces of the building? (Building spaces that are not normally occupied, but which are occasionally entered for repair or service of equipment, are considered to be occupied.)
5. Is the system once-through or recirculating?
6. Is it an ESF system (as defined by Regulatory Guide 1.52)[6] intended to mitigate the consequences of an accident?
7. What are the environmental considerations, that is, pressure, temperature, corrosion, etc.?

According to the answers to these questions, the duct should be constructed to conform to one of the several grades outlined in Table 5.5 and the leaktightness recommendations of Table 5.6. Recommended construction requirements are as follows:

Level 1: In accordance with SMACNA *Low Velocity Duct Construction Standards*,[4] except that button-punch and snap-lock seam and joint construction are not permitted; these constructions are considered unsuitable, even for low-pressure construction.[7] Companion-angle or bolted (or screwed) standing-seam transverse joints are recommended. Standing edges of seams or joints and reinforcement should be on the outside of the duct.[8] The use of level 1 ductwork is limited to systems serving administrative areas and other nonsafety-related applications in which maximum static pressure does not exceed 2 in.wg.

Level 2: In accordance with SMACNA *High Velocity Duct Construction Standards*,[4] except that (1) button-punch and snap-lock construction are not permitted; (2) only bolted flanged joints, companion-angle flanged joints, welded-flanged joints (in accordance with Fig. 5.1), or welded joints are permitted for transverse connections; (3) tie rods and cross braking are not permitted on

Table 5.5. Guide for selecting recommended duct construction levels for various applications in nuclear facilities[a]

| Contamination level and/or function[b] | Operating mode[c] | System type, duct location: Outside contained space, all systems, duct located in— Zone IV | Zone III | Zone II | Zone I | HVAC,[d] supply,[e] recirculating portion within contained space |
|---|---|---|---|---|---|---|
| None, supply, HVAC | A | 1 | 1 | 2 | 2 | 2 |
| | B | 1 | 1 | 1 | 1 | 1 |
| Low (class 4) | A | 3 | 2 | 2 | 2 | 2 |
| | B | 1 | 1 | 2 | 2 | 1 |
| Moderate (class 3) | A | 4 | 3 | 2 | 2 | 2 |
| | B | 4 | 2 | 2 | 2 | 1 |
| High (class 2) | A | 4 | 4 | 4 | 4 | 2 |
| | B | 4 | 4 | 4 | 4 | 2 |
| Very high (class 4) | A | 4 | 4 | 4 | 4 | 2 |
| | B | 4 | 4 | 4 | 4 | 2 |
| Process off-gas | A | 5 | 5 | 5 | 4 | 2 |
| | B | 5 | 5 | 4 | 4 | 2 |
| Controlled atmosphere[f] | A | 5 | 5 | 5 | 5 | 5 |
| | B | 5 | 5 | 5 | 5 | 5 |
| ESF control[g] | A | 4 | 4 | 4 | 4 | 2[h] |
| ESF control room | A | 4 | 4 | 4 | 4 | 2[h] |
| Other ESF | A | 4 | 3 | 3 | 3 | 2[h] |

[a]Duct construction level: 1, SMACNA low velocity; 2, SMACNA high velocity; 3, improved SMACNA high velocity; 4, welded; 5, pipe or welded duct, zero leak.
[b]Contamination levels, from Table 2.1.
[c]Operating mode: A, system to operate following upset or accident; B, system shutdown in event of upset or accident.
[d]HVAC: heating, ventilating, and air conditioning; building enclosure zones, from Table 2.3 and Sect. 2.2.1.
[e]Contained space: the building area or enclosure served by the system.
[f]Inert gas, desiccated air, or other controlled medium.
[g]HGTS, shield building exhaust, or other primary or secondary containment postaccident air cleanup systems.
[h]Duct must be structurally designed to function following a DBA or safe shutdown earthquake.

negative-pressure ducts; (4) standing edges and reinforcement of seams and joints are on the outside of ducts only; (5) sheet-metal thicknesses and reinforcement of negative-pressure ducts should be in accordance with Tables 5.1 through 5.5; and (6) radiation-resistant sealants (e.g., silicone room temperature vulcanizing) are required in the makeup of unwelded seams and in penetrations of safety-related ductwork. The use of level 2 ductwork is limited to systems serving administrative areas and Zone I and II areas, in which the radiotoxicity of materials handled or that could be released to the ductwork does not exceed hazard class 2 (Tables 2.1 through 2.3), and in which negative pressure does not exceed 10 in.wg static.

Level 3: Same as level 2 except that (1) transverse joints shall have full-flanged face width, $^1/_4$-in.-thick gaskets (ASTM D1056[9] grade SCE-45 cellular neoprene; 30–40 durometer, Shore-A, solid neoprene; or equivalent silicone elastomer) with interlocking notched corners (Fig. 5.1); and (2) nonwelded longitudinal seams, transverse joints, or the entire exterior may have hard-cast treatment (polyvinyl acetate and gypsum tape system) or comparable fire-resistant, corrosion-resistant, radiation-resistant, nonpeeling, leaktight treatment.

Level 4: All-welded construction except with sufficient mechanical transverse joints to facilitate coating (painting), erection, and future modifica-

Table 5.6. Recommended maximum permissible duct leak rates at 2 in. wg[a] negative (by methods of ANSI N510)

| Duct class | Maximum permissible leak rate |
|---|---|
| Level 1 | 5% of system airflow per minute |
| Level 2 | 1% of system airflow per minute |
| Level 3 | 0.2% of volume per minute[b] |
| Level 4 | 0.1% of volume per minute[b] |
| Level 5 | Zero detectable leak at any test pressure up to 20 in.wg |
| Recirculating | Leak test not required if totally within contained space served by air cleaning system |

[a]Maximum permissible leak rate at pressures greater than 2 in.wg is found from the equation

$$L_p \times L_2\sqrt{P'/2}$$

where

$L_p$ = permissible leak at higher pressure,
$L_2$ = permissible leak at 2 in.wg, from table,
$P'$ = higher pressure.

[b]Based on volume of portion of system under test.

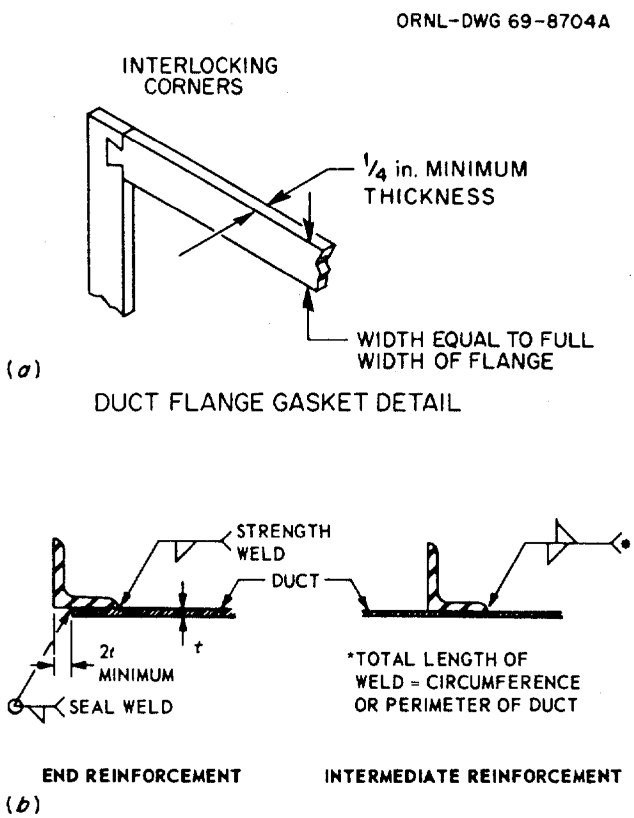



Fig. 5.1. Method of welding reinforcing and flange angles to negative pressure ductwork. Note skip welds on back of angles to prevent duct casing from pulling away from angle.

tion and/or dismantling. Mechanical transverse joints to conform to Fig. 5.1. Sheet-metal thicknesses and reinforcement taken from Tables 5.1 through 5.4 or determined by engineering analysis. ESF ductwork to meet requirements of Sect. 5.10 of ANSI N509.[5]

**Level 5**: Level 4 ductwork meeting requirements for leaktightness of level 5 duct (Table 5.6), or pipe meeting requirements of the *American National Standard for Pressure Piping*[10] or the *ASME Boiler and Pressure Vessel Code.*[11]

### 5.2.3 Engineering Analysis

When sheet-metal thickness and reinforcement are established from engineering analysis rather than from Tables 5.1 through 5.4, a design pressure of at least 1.25 times the normal operating pressure is necessary for level 1, 2, and 3 constructions. A design pressure of 1.5 times the maximum negative pressure that can exist in the particular run of duct, under the most adverse conditions to which it can be subjected under any conceivable conditions, including the DBA and safe shutdown earthquake (SSE), is recommended. The maximum negative pressure is generally the fan shutoff pressure. In the engineering analysis, the following loadings should be considered as applicable to the particular system under consideration:

1. Differential pressure across the duct wall, as affected by maximum internal and external pressures that could prevail during testing and under normal and abnormal operating conditions, and any increase or decrease in the pressure due to inadvertent closure of a damper or plugging of an internal component. For ductwork located within the containment vessel of a reactor, the external pressure under DBA conditions, due to the lag of pressure rise within the ductwork during the pressure transient in the containment vessel, must also be considered (such overpressures may be alleviated through the use of pressure-relief dampers that discharge to the containment space).
2. Effects of natural phenomena, including tornado and earthquake (Chap. 9), for ESF ductwork.
3. Thermal expansion.
4. Weight of the ductwork, including all attachments.

5. Weight of personnel walking on large ductwork only. Where this situation is likely to occur, duct sections with exposed top surfaces should be capable of supporting a 250-lb weight concentrated midway between the hangers or reinforcement, without permanent deformation. The out-of-roundness produced by such loading could lead to a sudden collapse of round duct when operating under negative pressure.

A maximum allowable stress of 0.7 times the elastic limit is recommended for the design of ductwork; maximum deflections under normal operating conditions should be

**Rectangular duct:** 0.125 in./ft of maximum unsupported panel span in the direction of airflow but not greater than 0.75 in. Deflection of reinforcement—0.125 in./ft of span but not more than 0.75 in. across total span.

**Round duct:** 0.0625 in./ft of diameter, but not more than 0.5 in. at any point.

### 5.2.4 Materials of Construction

Ductwork may be made from painted or coated carbon steel, galvanized steel, aluminum, stainless steel, or any combination of these materials required to resist corrosion in the service environment. Glass-fiber-reinforced plastic (GFRP) and epoxy ducts have been used in corrosive environments where fire and safety requirements permit and may be less expensive than stainless steel, lined carbon steel, or epoxy- or vinyl-coated carbon steel. Although GFRP duct has been approved by the National Fire Protection Association and Underwriters' Laboratories for commercial and industrial use,[12] even high-temperature resins will soften under brief exposure to temperatures of 350° to 450°F.[13] Softening of GFRP duct can lead to rapid collapse or distortion, followed by loss of air cleaning function. GFRP and other plastic ductwork should not be used for level 3, 4, or 5 construction and should be used with caution for levels 1 and 2.

### 5.2.5 Paints and Protective Coatings

Coating and paint requirements must be consistent with corrosion that can be expected in the particular application and with the size of the duct. Corrosion- and radiation-resistant paints and coatings should, as a minimum, meet the requirements of ANSI N512 for "light exposure."[14] Unless special spray heads are used, spray coating of the interior of ducts smaller than 12 in. in diameter is often unreliable, because it is difficult to obtain satisfactory coating and to inspect for defects and "holidays." The interior of duct 8 in. and smaller cannot be satisfactorily brush-painted; therefore, dip coating is recommended. Ducts to be brush-painted should be no longer than 5 or 6 ft to ensure proper coverage. When special coatings, such as the high-build vinyls and epoxys, are specified, the designer must keep in mind that the difficulties in surface preparation, application, and inspection may increase the cost of coated carbon steel to the point that stainless steel may be economically competitive, as well as perhaps providing better protection. An important point is that high-build coatings and paints can be damaged during handling and shipping and that corrosion can begin under such damaged areas without the user's knowledge. Painted and coated ductwork must be inspected carefully during the painting (coating) operation and also on receipt. Galvanized coatings and plates should also be carefully inspected, particularly on sheared edges and welds. Defects and "holidays" in such areas must be touched up with zinc-rich primer and top coat before the system is placed in service (see also Sect. 4.5.11).

### 5.2.6 Hangers, Supports, and Anchors

Non-ESF ductwork can be hung, supported, and anchored in accordance with the recommendations of Chap. 5 of the SMACNA *High Velocity Duct Construction Standards*,[4] with the following exception: anchors and attachments which rely on an interference-fit between, or deformation of, the base material (concrete roof deck, beam, etc.) and the attachment device (as is the case for powder-actuated drive bolts and studs and for concrete anchors) should not be used for safety-related ductwork. Support requirements for ESF ducts and other ductwork that must remain in place in the event of an earthquake or major accident must be established by modeling or engineering analysis. Such analysis must be based on the inputs (forces, accelerations) to the building element to which the duct is fastened or from which it is hung (i.e., floor, wall, roof deck, etc.) that will be produced by a DBA or SSE, or both. Non-ESF ductwork located above or adjacent to other ESF equipment of the facility, which could damage such equipment if it fell, is also subject to this restriction.

### 5.2.7 Acoustic Treatment of Duct

Acoustic linings and duct silencers are not permitted in safety-related ducts or ducts which carry, or may carry, moisture or corrosive fumes. Acoustic treatment, if required, must be attached to the exterior of the duct.

### 5.2.8 Duct Leakage

Leaktightness of ductwork, particularly in systems that carry or have the potential of carrying radioactive material, is extremely important. Duct leakage wastes power and thermal energy (i.e., energy required to heat, cool, or dehumidify air), causes noise, prevents correct airflow to outlets from inlets, makes difficult the balancing of systems and controlling of temperature and humidity, and produces unsightly dirt collections and radioactive contamination at leakage sites. The Carrier Corporation's *System Design Manual,* in discussing ductwork equivalent to levels 1 and 2, states:[15]

> Experience indicates that the average air leakage from the entire length of low velocity [positive pressure] ducts, whether large or small systems, averages around 10% of the supply air quantity. Smaller leakage per foot of length for larger perimeter ducts appears to be counterbalanced by the longer length of run. Individual workmanship is the greatest variable, and duct leakages from 5% to 30% have been found....High velocity duct systems [Level 2] usually limit leakage to 1%.

Even 1% is excessive for systems that carry or have the potential of carrying intermediate- to high-level radioactivity. Leak rates based on the percentage of airflow are meaningless and subject to misinterpretation. Duct tightness is generally tested by sealing off sections of the system which are then individually tested by either the direct-measurement or pressure-decay method of ANSI N510.[16] With such procedures, a leakage criterion based simply on percentage of airflow can produce anomalous results. By such a criterion, two duct systems built to the same construction standards and having the same volume and surface area but different airflow rates could have widely differing permissible leakages (PL). Conversely, if the airflow rates are the same but the volumes differ, they could have widely differing PLs. For this reason, a PL based on duct volume, as has been used in AEC (subsequently ERDA) installations for many years, or a PL based on the surface area of the pressure boundary of the section under test is recommended. Table 5.6 gives permissible leak rates for the various levels of construction, including the values that have been recommended over the years for nuclear grade ductwork.[17] The values for levels 3, 4, and 5 ductwork are more stringent than those recommended for ductwork in nuclear power plants by ANSI N509.[5]

The leak rates cited by Carrier[17] were for positive-pressure ductwork; the same ducts, tested at the same degree of negative pressure, would have leaked many times more. In tests conducted at an ERDA facility,[18] sections of level 2 ductwork tested alternately at 2.5 in.wg positive and 2.5 in.wg negative by the pressure-decay method showed no pressure loss in 15 min under positive pressure but a loss of 2 in.wg in 15 min under negative pressure. This tendency for the same ductwork to leak substantially more under negative pressure than under positive pressure is confirmed by SMACNA.[19] It is recommended that leak tests be made under negative pressure if possible and at the normal discharge pressure or suction pressure of the fan insofar as is practicable. These leak rates are predicated on the potential for outleakage of contamination to occupied areas of the facility should the ductwork or filter housing become pressurized under system upset conditions.

## 5.3 DAMPERS

### 5.3.1 Damper Specification

Dampers are the valves of the air cleaning and ventilation system. By definition, a damper is any device that controls pressure, direction, or volume of airflow in a ventilation system, including those items normally classed as valves when used in piping systems.[5] Clear, concise specifications must be established for mechanical strength, for leakage rate at maximum (i.e., DBA) operating conditions, and for the ability to perform under required operational and emergency conditions. Operability of linkages must be assured through specification of and requirement for cycling at minimum torque requirements under full load; static testing of the closed damper should be required, where applicable, for those to be used in critical applications to verify strength and leaktightness. All features important to proper operation should be stipulated in detail, including materials of construction, permissible lubricants, bearings, blade design and edgings (if permitted), indicating and locking quadrant, supports, operator type and capability, and the accessibility of operator, linkages, blades, and bearings for maintenance.

Factors that must be considered in the selection or design of dampers for nuclear applications include function of damper; type of construction; dimensions and space limitations; pressure drop across closed damper; normal blade operating position; method of mounting damper; blade orientation relative to damper case; operator type and power source; seismic requirements; requirements for position indicator, limit switches, and other appurtenances; configuration of damper; permissible leakage through closed damper; space required for service; airstream temperature range; orientation of damper in duct; direction of airflow; failure mode and blade position; maximum closing and opening times; and method of shaft sealing.

In conventional air conditioning and ventilating applications, procurement of dampers has generally been accomplished by specifying little more than the manufacturer's make and model number "or approved equal." This is poor specification practice under any circumstances and is inadequate for nuclear and other potentially high-risk applications. Therefore, a method of damper specification based on classification of important features was developed for this handbook. The classification method was further refined by ANSI Subcommittee N45.8 on components and testing of nuclear air cleaning systems and is included in ANSI N509.[5] The classification enables the designer to make a rational selection of dampers, independent of manufacturer's make and model number, for a specific application. By appropriate selection of the classifications from Tables 5.7 through 5.11, a specification can be written to serve as the basis for both design and procurement.

### 5.3.2 Description and Application of Dampers

Requirements for a damper for a specific application can be stated by combining the classification symbols; for example, fc/so-1-C-III-E specifies a flow-control, shutoff, parallel-blade, industrial-quality, leak group III damper with electric motor operator. Having established the requirements of the damper, plus the duct dimensions, airflow requirements, and system static pressure, the vendor can then select an item from his line which is suitable for the application. Table 5.12 gives recommended damper requirements for various types of nuclear air cleaning systems. Typical dampers used in critical service applications are shown in Figs. 5.2 and 5.3. A large butterfly damper is shown in Fig. 5.4.

### 5.3.3 Damper Design and Fabrication

Class A and B dampers differ only in that class A must meet the requirements for materials, fabrication, inspection, and testing of the ASME Code.[20]

Table 5.7. Classification of dampers by function

| Designation | Function |
|---|---|
| fc | **Flow control damper.** One which can be continuously modulated to vary or maintain a given level of airflow in the system in response to a feedback signal from the system or from a signal fed to the damper operator by means of a manually actuated control or switch. |
| pc | **Pressure control damper.** One which can be continuously modulated to vary or maintain a given pressure or pressure differential in the air cleaning system or in a building space served by the system in response to a signal. |
| b | **Balancing damper.** One which is set (usually manually) in a fixed position to establish a baseline flow or pressure relationship in the air cleaning system or in building spaces served by the system. |
| so | **Shutoff damper.** One which can be completely closed to stop airflow through some portion of the system, or opened partially or fully to permit airflow (the fc damper may also serve this function). |
| i | **Isolation damper.** A high-integrity shutoff damper used to completely isolate a portion of a system from a contained space or from the remainder of the system with a leaktight seal. |
| bd | **Back draft damper.** One which closes automatically or in response to a signal to prevent flow reversal. |
| pr | **Pressure-relief damper.** One which is normally closed but will open in response to overpressure in the system or in the contained space served by the system in order to prevent damage to the system. |

Class A and B dampers may be either forged or cast-body, liquid-service, pipeline valves, or heavy-duty, industrial-quality, conventional units that can meet the leaktightness and pressure requirements as specified. Body and flanges of fabricated class B dampers are generally of welded construction and made from structural shapes; otherwise, requirements are similar to those for class C dampers.

Class C dampers are of heavy industrial-quality construction, with bodies made from structural channels or channels die- or roll-formed from heavy steel sheet or plate. The body should be no less than 4 in. wide with 1.25-in.-wide (or wider) flanges on both faces. Deflection of the body sides under the maximum differential pressure to which the damper will be subjected under normal or accident conditions should not exceed 0.3% of the length of the side.

Table 5.8. Classification of dampers by configuration

| Designation | Configuration |
|---|---|
| 1 | **Parallel blade damper.** A multiblade damper having blades that rotate in the same direction (AMCA 500).[a] |
| 2 | **Opposed blade damper.** A multiblade damper having adjacent blades that rotate in opposite directions (AMCA 500).[a] |
| 3 | **Butterfly damper.** A heavily constructed damper, often a valve used in piping systems and usually round in cross section, designed for high-pressure service (25 psi minimum pressure rating), with one centrally pivoted blade that can be sealed to meet the requirements of Leak Group I (Table 5.10). |
| 4 | **Single-blade balanced damper.** A damper, usually round in cross section, with one centrally pivoted blade. |
| 5 | **Single-blade unbalanced damper.** An accurately fabricated, often counterbalanced damper, usually rectangular in cross section, with one eccentrically or edge-pivoted blade. |
| 6 | **Folding blade or wing blade damper.** A damper with two blades, pivoted from opposite sides of a central post, which open in the direction of airflow. |
| 7 | **Poppet damper.** A weight or spring-loaded poppet device that opens when the pressure differential across it exceeds a predetermined value. |
| 8 | **Slide or gate damper.** A damper similar to a gate valve, with a single blade that can be retracted into a housing at the side of the damper to partially or fully open the damper. |

[a]AMCA 500, *Test Methods for Louvers, Dampers, and Shutters*, Air Moving and Conditioning Association, Arlington Heights, Ill., 1975.

Table 5.9. Classification of dampers by construction

| Designation | Construction |
|---|---|
| A | **Code damper.** A valve meeting the requirements for class 2 or 3 components (whichever is specified) of Sect. III of the *ASME Boiler and Pressure Vessel Code*;[a] or a heavy-duty fabricated-construction damper designed for a service rating of at least 25 psi, having a die-formed or structural-shape body and flanges and meeting the requirements for materials, fabrication, inspection, and testing in accordance with the requirements for class 2 or 3 valves of Sect. III of the *ASME Boiler and Pressure Vessel Code*.[a] |
| B | **High-pressure damper.** A valve meeting the requirements of ANSI B31.1;[b] or a heavy-duty fabricated-construction damper designed for a service rating of at least 25 psi, having a die-formed or structural-shape body and flanges and meeting the requirements for materials, fabrication, and inspection of ANSI B31.1.[b] |
| C | **Industrial-grade damper.** A heavy-duty, fabricated-construction damper having a die-formed or structural-shape body and flanges. |
| D | **Commercial-grade damper.** A lightly built, fabricated-construction damper for low-to-medium pressure duty (6 in.wg) having a die-formed or roll-formed body and having flanges when specified. |

[a]*ASME Boiler and Pressure Vessel Code*, Sect. III, Div. 1, "Nuclear Power Plant Components," Subsection NC, "Class 2 Components," and Subsection ND, "Class 3 Components," American Society of Mechanical Engineers, New York, current issue.

[b]ANSI B31.1, *Power Piping*, American National Standards Institute, New York, current issue.

Blade shafts should be made from solid steel bar and should extend the full width of the blade and journals. Blades should be made from heavy steel sheet (generally at least No. 11 U.S. gage) or plate and should be welded or through-bolted to the shafts in such a manner that the integrity of the attachment can be verified by visual inspection after assembly of the damper. Deflection of blades and shafts should be no more than 0.3% of the free span with the blades in the closed position and under a differential pressure of at least 1.5 times the design pressure to which they will be subjected under maximum service conditions (DBA conditions for those dampers that must operate during and following an emergency or accident). Sealing materials applied to blade edges and seats must be radiation-resistant and readily replaceable. Linkages of class C dampers should be located outside the airstream, should be made from steel bar, and should be structurally designed to transmit at least twice the maximum force that can be produced by the operator without exceeding an allowable stress of 0.7 times the yield strength of any part. The minimum length of any linkage arm of an industrial-quality damper should be 3 in. Bearings should be of the flange-mounted, lubricant-impregnated, sintered-bronze journal type or rolling-element type and should be designed to operate at the specified service temperature or 200° F, whichever is higher. Rolling-element bearings should be used for service temperatures higher than 200° F and should have grease fittings that are accessible from the outside of the damper after it has been installed in the duct system. Shafts must be sealed to maintain a

Table 5.10. Classification of dampers by leaktightness

| Damper blade length or diameter (in.) | Designation: Maximum permissible leak rate (scfm/ft²) of internal cross section at 1 in.wg $\Delta p$ across closed damper[a] | | | | |
|---|---|---|---|---|---|
| | Group I | Group I-A | Group II | Group III | Group IV |
| 12 | Bubble-tight | 2 | 15 | 60 | *b* |
| 24 | at pressure | 3 | 10 | 40 | *b* |
| 36 | specified by | 4 | 8 | 32 | *b* |
| 48 | purchaser | 4 | 6 | 32 | *b* |
| 60 | | 4 | 6 | 27 | *b* |
| 72 | | 4 | 5 | 25 | *b* |

[a]Leak tests are not applicable to balancing dampers unless specified by purchaser. Interpolation may be used to find permissible leak rates for intermediate-size dampers. Use multiplying factors below to find permissible leak rates at higher differential pressures; class A and B dampers should be tested at design pressure or 12 in.wg, whichever is lower. Class C dampers should be tested at design pressure.

[b]Damper leakage is not a factor; a leak test is not required.

| Differential pressure (in.wg) | Multiplying factor | Differential pressure (in.wg) | Multiplying factor |
|---|---|---|---|
| 2 | 1.4 | 7 | 2.6 |
| 3 | 1.7 | 8 | 2.8 |
| 4 | 2.0 | 9 | 3.0 |
| 5 | 2.2 | 10 | 3.2 |
| 6 | 2.4 | 12 | 3.5 |

Table 5.11. Classification of dampers by operator type

| Designation | Operator type |
|---|---|
| M | Manual operator—lever on damper with indicating quadrant |
| C | Manually controlled chain operator to permit remote adjustment |
| E | Electric motor operator |
| H | Hydraulic operator |
| P | Air (pneumatic) operator |

degree of leaktightness commensurate with leakage for level 3, 4, and 5 duct systems.

Class D dampers are of light sheet-metal, commercial-quality construction. Dampers for level 2 and higher ductwork must have flanges to permit mounting between sections of duct. Flange installation is also preferred in level 1 ductwork. Damper body should be made from No. 16 U.S. gage or heavier sheet metal, die- or roll-formed into channel cross section. Flange width should be 1¼ to 1½ in. as required to meet duct construction standards (Fig. 3-15 in ref. 4, SMACNA *High Velocity Duct Construction Standards*). Single-thickness blades should be made from at least No. 16 U.S. gage sheet metal, and double-thickness blades should be at least 18 gage. The maximum unsupported blade length should be 48 in., and the blade width of multiblade dampers should not exceed 9 in. Shafts should be at least 7/16 in. in diameter and fitted with lubricant-impregnated, sintered-bronze journal bearings or rolling-element bearings. Linkages may be mounted either in or outside of the

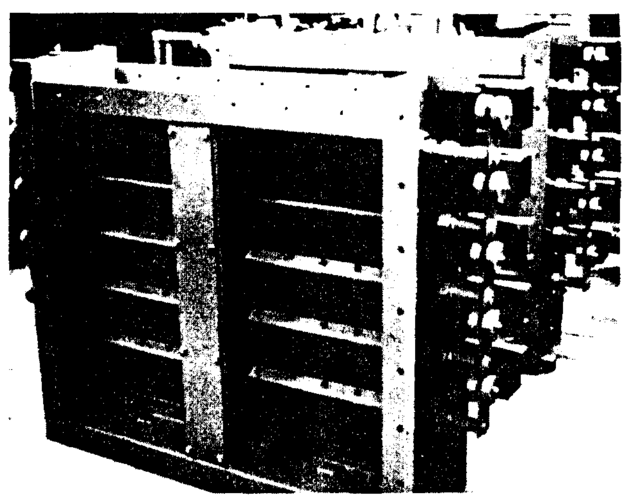


Fig. 5.2 Heavy-duty, industrial-grade, parallel blade damper.

Table 5.12. Damper requirements[a]

| Damper function[b] | Damper properties[c] | | | | |
|---|---|---|---|---|---|
| | Level of duct system (Table 5.6) | | | | |
| | 1 | 2 | 3 | 4 | 5 |
| Flow or pressure control | | | | | |
| Construction class | D | D | D | C | A,B |
| Leakage group | III | III | II | II | I |
| Suggested configuration | 2,4,8 | 2,4 | 2,4 | 2,4 | 2,4 |
| Balancing | | | | | |
| Construction class | D | D | D | C | A,B |
| Leakage group | IV | IV | IV | IV | VI |
| Suggested configuration | 1,4,8 | 1,4 | 1,4 | 1,2,4 | 1,2,4 |
| Shutoff | | | | | |
| Construction class | D | D | D | B,C | A,B |
| Leakage group | III | III | II | I-A | I |
| Suggested configuration | 1,2,4,8 | 1,2,4 | 1,2,4 | 3 | 3 |
| Containment isolation | | | | | |
| Construction class | | | | A | A |
| Leakage group | | | | I | I |
| Suggested configuration | | | | 3 | 3 |
| Unit or system isolation | | | | | |
| Construction class | D | C | C | B | A,B |
| Leakage group | II | I-A | I-A | I | I |
| Suggested configuration | 1,2,4,8 | 1,2,4,8 | 1,2,4 | 3 | 3 |
| Back draft prevention | | | | | |
| Construction group | D | D | D | C | A,B |
| Leakage class | III | III | II | I-A | I |
| Suggested configuration | 1,5,6 | 1,5,6 | 1,5,6 | 1,5,6 | 5,6 |
| Pressure relief | | | | | |
| Construction group | D | D | D | | |
| Leakage class | III | II | I-A | | |
| Suggested configuration | 1,5–7 | 1,5–7 | 1,5–7 | | |

[a]Requirements for damper classifications as defined in Sect. 5.3.

[b]Where a damper serves more than one function (e.g., flow control and shutoff), requirements for the more stringent service apply.

[c]Configuration other than those shown may be used if leakage characteristics and construction are equivalent or better.

airstream and should have a minimum lever-arm length of 1 in. in any member.

### 5.3.4 Damper Operator

In most cases operators should be installed outside of the airstream, and they should always be factory-mounted by the damper manufacturer. Torque requirements based on operating conditions specified by the user should be established by the damper manufacturer. The operator should be capable (1) of producing a minimum of 1.5 times the torque required to move the blades from full-open to full-closed and (2) of meeting the specified leaktightness in the closed position under the maximum service conditions (normal operating or system upset, whichever is specified) the damper will have to operate. Dampers in which the blade shafts penetrate the body should have a mechanical position-indicating device (e.g., pointer and escutcheon plate). Dampers that will be controlled remotely should also be equipped with switches, relays, or other devices to produce a position-indication signal that can be transmitted to the central control station.

### 5.3.5 Qualification and Acceptance Testing

Qualification consists of prototype or preproduction model tests to verify design and/or to establish

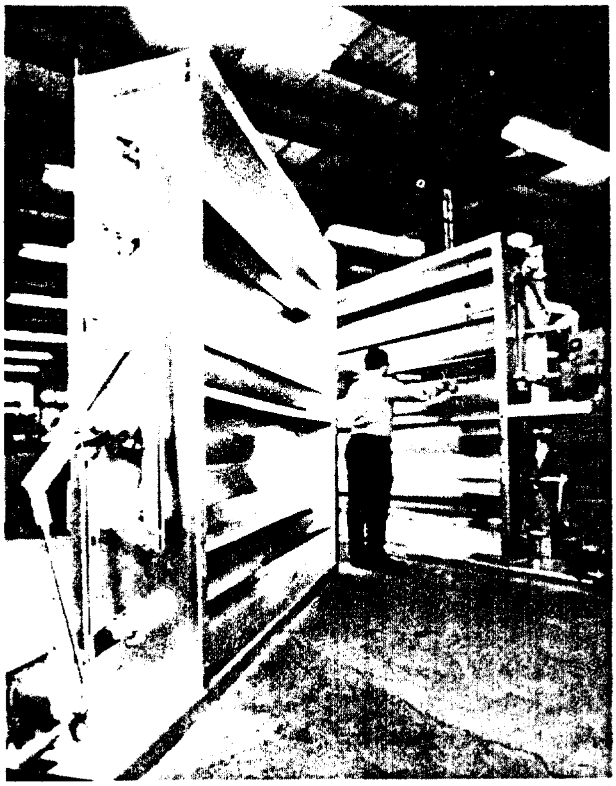


Fig. 5.3 Heavy-duty, industrial-grade, opposed blade dampers for nuclear service. Courtesy American Warming and Ventilating Co.

Fig. 5.4. Large butterfly damper for nuclear isolation service. Courtesy American Warming and Ventilating Co.

performance and operational characteristics of the design. In the case of AMCA-rated dampers,[21] these tests consist essentially of pressure-drop and airflow determinations at various degrees of blade opening.[22] The AMCA rating is generally sufficient evidence that suitable qualification tests have been made. For dampers not listed by AMCA, the manufacturer should be required to provide performance data obtained under conditions equivalent to those used in the AMCA test code.[22] For valves (construction classes A and B), equivalent test data are often available for both water and gas flow. A particularly important piece of information to be obtained by qualification testing is the resistance of the fully open damper and the resistance vs blade-position curve from full-open to full-closed. These resistances must be included in the air cleaning system design calculations in the same manner as other system resistances.

Production units are subject to acceptance tests to verify that the units are in good operating condition. Repetition of qualification tests to demonstrate operational characteristics is generally unnecessary and unwarranted. A damper to be used in a level 4 or 5 duct system that will be or may be exposed to high levels of contamination should be cycled through the full range at least 25 times, with all accessories attached, to verify the free and correct operation of all parts and the correct adjustment, positioning, and seating of the blades. Adjustments should be made as necessary during the test to correct deficiencies. Shop leakage tests may be desirable, particularly for zero-leak (group I) and some group II dampers. Such tests should be made after successful completion of the cycling test. Dampers that perform a containment-vessel-isolation function should always be leak-tested in the shop prior to acceptance. Because damper operators are generally furnished to the damper manufacturer as a purchased item, a test to verify the torque characteristics of the operator, after installation on the damper in its service position, is desirable, particularly for control, shutoff, and isolation dampers at critical locations in the system.

## 5.4 FANS

### 5.4.1 Fan and System Curves

A major requirement for a fan operating in a high-efficiency air cleaning system is its ability to perform safely and efficiently over a much larger variation of resistance than more conventional ventilation systems. This variation of resistance is caused by dust loading of the HEPA filters and may double from the time of filter installation to the time of filter change, or may increase as much as five times in some systems (see discussion of operation to high pressure drop, Sect. 2.3.5). The increase in resistance across the HEPA filters is usually the major factor influencing the pressure-flow relationships (represented by the numbered curves in Fig. 5.5) of high-efficiency air cleaning systems. Fan performance (airflow vs pressure capability) and system resistance vs airflow are represented by characteristic curves such as curves A, 1, and 2 of Fig. 5.5. The volume of air that can be delivered by the fan is determined by the intersection of the fan and system characteristic curves; the flow represented by this point of intersection is the only flow that can be delivered by the fan under the given operating conditions. In most cases, a fan with a steeply rising characteristic (curve A, Fig. 5.5) is desirable to maintain reasonably constant airflow in the system over the entire life of the HEPA filters. If a fan with a broad, flat characteristic is chosen, it will be less able to deliver the required airflow as the filters become dust-loaded (curve 1 to curve 2), and either system performance (i.e., airflow) or filter life will have to be sacrificed. Any decrease in filter life will, of course, be accompanied by higher change frequency and therefore increased operating (maintenance) costs. If a pressure-equalizing device (damper) is installed to balance system pressure against filter pressure drop in order to maintain a constant pressure-airflow relationship in the system, a penalty in operating (power) costs will result.

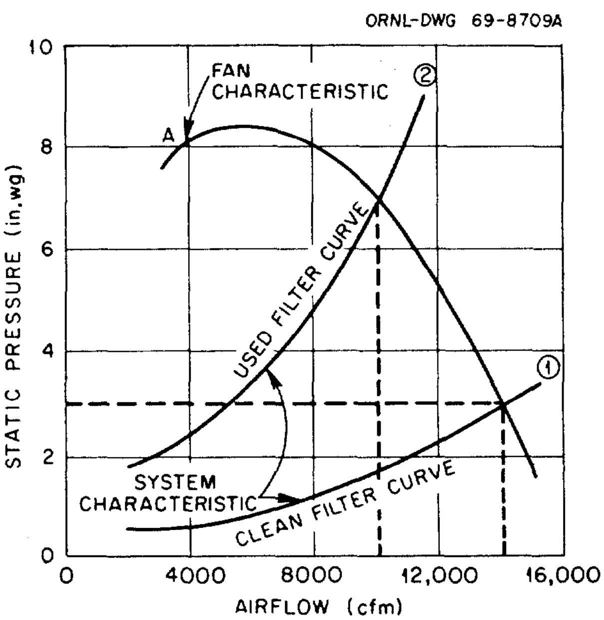



**Fig. 5.5. Fan and system characteristic curves showing relationships between airflow delivery and resistance.** With no dampers to adjust system resistance, airflow drops from 14,000 cfm, when new filters are installed (intersection of curves A and 1, $\Delta p$ = 3 in.wg) to 10,000 cfm when they are replaced at an economic filter resistance increase of 4 in.wg (intersection of curves A and 2, system $\Delta p$ = 7 in.wg).

### 5.4.2 Fan Performance—System Effect

The inability of fans to perform in the field in accordance with published ratings has long troubled the industry. The problem arises partly because the ratings are based on idealized laboratory conditions that are rarely encountered in the field, and partly because of design and/or field compromises made to accommodate the field situation. Many of the problems of fan operation stem from poorly designed connections to the duct. Close-coupling, too short transitions between unmatched (in size) duct and fan inlets, square-to-round connections, and poorly designed inlet boxes create a vortical or eccentric flow into the fan impeller and result in noise, vibration, and reduced efficiency. A 45° spin in the direction opposite fan rotation may reduce fan delivery as much as 25% and require a compensating increase in fan pressure of from 50 to 55%. Figure 5.6 shows the effects of various inlet conditions on fan performance and the resultant increase in fan capability (fan static pressure) to compensate for these effects. Too often these effects are not taken into account when calculating fan requirements, with the result that neither the fan nor the filters can perform to the desired design levels. Outlet connections also affect fan performance, as Fig. 5.7 shows.

To alleviate the situation, AMCA has published a *Fan Application Manual*, Part 1 of which includes a set of "system effect curves" by which the designer can predict the effects of design features (such as the inlet and outlet conditions illustrated in Figs. 5.6 and 5.7) on fan performance and, when needed, make allowance for them in initial fan selection.[23] System effects are the losses in fan performance that result from the fan being installed in a less than ideal configuration. These effects must be taken into account by the designer if a realistic estimate of fan performance under conditions of the "real life" system is to be made. Figure 5.8 illustrates a deficient fan-system interaction resulting from one or more undesirable design conditions. The assumption is made that pressure losses in the duct system have been accurately estimated (point 1, curve A), and a suitable fan, based on published ratings, has been selected for operation at that point. However, no allowance has been made for the effect of the fan connections on fan performance, that is, of the interaction between the fan and the system as designed. To compensate for the system effect loss

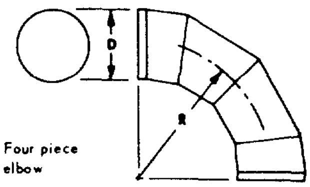
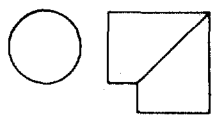
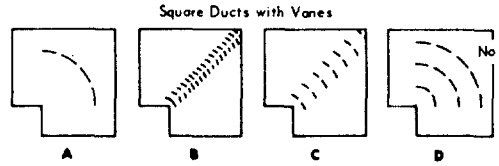
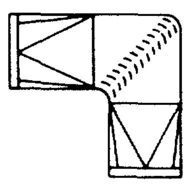
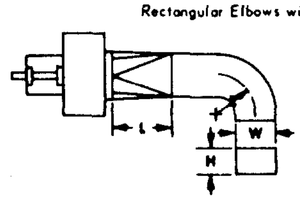
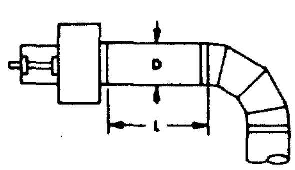
| DESCRIPTION | PERCENT LOSS IN CFM IF NOT CORRECTED | PERCENT INCREASE NEEDED IN FAN SP TO COMPENSATE |
|---|---|---|
|  Four piece elbow | | |
| Three piece elbow $R/D = 0.5$ | 12 | 30 |
| 1.0 | 6 | 13 |
| 2.0 | 5 | 11 |
| 6.0 | 5 | 11 |
| Four piece elbow $R/D = 1.0$ | 6 | 13 |
| 2.0 | 4 | 9 |
| 8.0 | 4 | 9 |
| Five piece elbow $R/D = 1.0$ | 5 | 11 |
| 2.0 | 4 | 9 |
| 8.0 | 4 | 9 |
|  Mitered elbow | 16 | 42 |
| Square Ducts with Vanes  | | |
| No Vanes | 17 | 45 |
| A | 8 | 18 |
| B | 6 | 13 |
| C | 5 | 11 |
| D | 4 | 9 |
|  Round to Square to Round | 8 | 18 |
| Rectangular Elbows without Vanes*  *In all cases use of three long, equally spaced vanes will reduce loss and needed sp increase to 1/3 the values for unvaned elbows. | | |
| $\frac{H}{W} = 0.25$, and $\frac{R}{W} = 0.5$ | 7 | 15 |
| 1.0 | 4 | 9 |
| 2.0 | 4 | 9 |
| $\frac{H}{W} = 1.00$, and $\frac{R}{W} = 0.5$ | 12 | 30 |
| 1.0 | 5 | 11 |
| 2.0 | 4 | 9 |
| $\frac{H}{W} = 4.00$, and $\frac{R}{W} = 0.6$ | 15 | 39 |
| 1.0 | 8 | 18 |
| 2.0 | 4 | 9 |
| The maximum included angle of any element of the transition should never exceed 30°. If it does, additional losses will occur. If angle is less than 30° and L is not longer than the fan inlet diameter, the effect of the transition may be ignored. If it is longer, it will be beneficial because the elbow will be farther from the fan. | | |
|  Each $2\frac{1}{2}$ diameters of straight duct between fan and elbow or inlet box will reduce the adverse effect approximately 20%. For example, if an elbow that would cause a loss of 10% in CFM or an increase of 23% in fan SP, if on the fan inlet, is separated from the fan by straight duct, the effect of the duct may be tabulated thus: No duct .......... Loss - 10% – SP needed = 23%<br>$L/D = 2\frac{1}{2}$ .......... Loss - 8% – SP needed = 19%<br>5 .......... Loss - 6% – SP needed - 13%<br>$7\frac{1}{2}$ .......... Loss - 4% – SP needed - 9%<br>10 .......... Loss - 2% – SP needed - 4% | | |

Fig. 5.6. Effect of fan inlet on fan performance. From C. J. Trickler, "Is the System Correctly Designed," *Air Cond. Heat. Vent.* 57, 87 (May 1960).

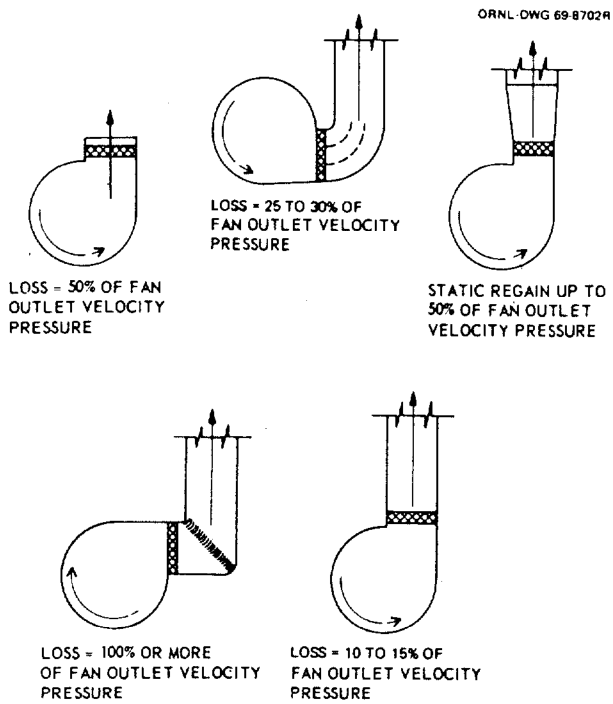



Fig. 5.7. Effect of fan outlet connection on fan performance.

because of the unfavorable interaction between the fan and its connections, it will be necessary to add a system effect factor to the calculated system pressure losses to determine the actual system characteristic curve and to determine the actual fan required to produce the required operating characteristics.

Testing to establish the capability of the fan in a nuclear air cleaning system as originally installed is recommended by ANSI N510.[16] Part 3 of the AMCA *Fan Application Manual*[24] provides guidelines for such testing, including examples of the application of system effect factors for various system configurations. Planes of measurement, measurements to be made, average test readings, calculation of test results, and corrections to overcome deficiencies disclosed by the tests are all covered in detail. It is preferable to apply system effect factors before selection, purchase, and installation of a fan to prevent the incorporation of unfavorable features into the system design. In applying system effect factors, it must be recognized that those factors given in the AMCA manual are only guidelines and general approximations, although many have been obtained from research studies. Fans of different types and fans of the same type, but made by different manufacturers, will not necessarily interact with the system in exactly the same way. It is necessary, therefore, to apply judgment based on experience in applying system effect factors. The appendixes to Part 3 of the AMCA *Fan Application Manual*[24] provide the background for such judgment factors.

### 5.4.3 Multiple Fan Installation

The installation of two fans in series is sometimes desirable where a steeply rising pressure-airflow characteristic is needed;[25] however, caution must be exercised in such design. In theory, the combined pressure-volume characteristic of two fans operating in series is obtained by adding the fan pressures at the same volumetric airflow as shown in Fig. 5.9. Care must be taken in designing the connection between the fans, because a significant loss of efficiency can occur in the second-stage fan due to nonuniform flow into its inlet, particularly if the two fans are closely coupled.

Two or more fans are often operated in parallel to move large volumes of air, to enhance the control of segmented air cleaning facilities, or to limit the installed capacity (i.e., filters, adsorbers) of any one unit of the air cleaning system. The combined volume-pressure curve in this case is obtained by adding the volumetric capacity of each fan at the same pressure (Fig. 5.10). If the ducts that feed the fans are independent (as, for example, arrangements 1c, 2c, or 3c of Fig. 2.9), the outputs of the fans will be additive. If the fans are fed from a common inlet box, as shown in Fig. 5.11, adverse interaction can take place, which may substantially reduce the output of the combination.

One concern in parallel fan installations is that some fans have a positive slope in their characteristic curves to the left of the peak pressure point (Fig. 5.10). If the fans are operated in the pressure-volume regime of this positive slope, unstable operation may result, as shown by the closed loop to the left of the peak pressure point in Fig. 5.10 (this loop is obtained by plotting all of the possible combinations of flow at each pressure). If the system characteristic curve intersects the fan characteristic in the area of this loop, more than one point of operation is possible; this may cause one of the fans to handle more of the system load (airflow) than the other and result in a motor overload. The unbalanced flow condition tends to shift rapidly so that the fans intermittently load and unload. The pulsing that results from such loading and unloading generates noise and vibration and may cause damage to the fans, motors,

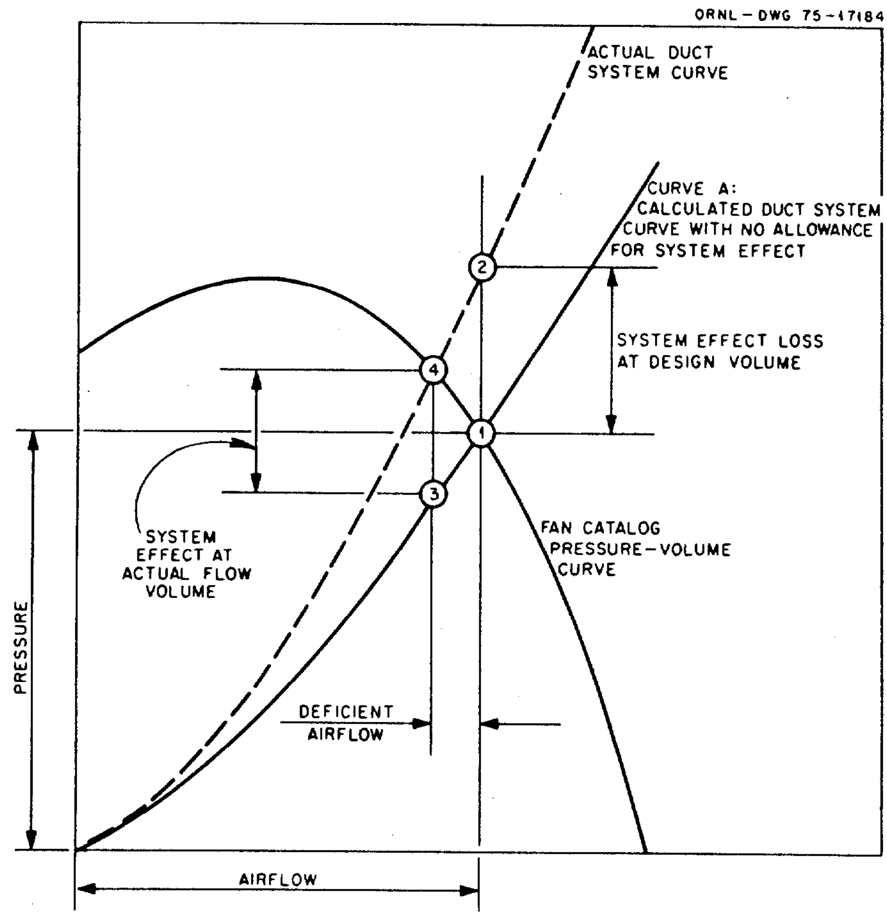



**Fig. 5.8. Result of selecting a fan on the basis of manufacturer's ratings.** Poor interaction between selected fan and system, due to poor inlet and/or outlet design, results in system effect loss at design volume. This loss must be added to the calculated system resistances to determine the total system losses on which to base fan selection. Courtesy Air Moving and Conditioning Association.

ductwork, or filters. Aileron controls in the fan outlets, or the provision of dampers near the inlets or outlets, may sometimes be sufficient to correct unbalanced flow or to eliminate pulsing and/or reversing operation.

### 5.4.4 Fan Capacity

Experience has shown that fans are often unable to meet the actual demands of the system as they are installed; therefore, sacrifices in performance and efficiency result. Poor fan selection may be a result of either underestimating actual system losses or failure to recognize fan/system interaction (i.e., system effects). In push-pull systems (i.e., systems containing both supply and exhaust fans that operate at the same time), exhaust fan capacity should be at least 10% greater than supply fan capacity to compensate for infiltration, pressure surges, wind effects (i.e., pressure variations in the building and ductwork due to variable wind conditions exterior to the building), and temperature variations, and to eliminate any possibility of overpressurizing the building by the supply fans.

Improper fan operation can be avoided by carefully evaluating system pressure drops and interactions under all predictable operating conditions and by specifying a type and size of fan that matches the demands of the duct system as installed. Control must be exercised over the installation of ducts and fans to prevent field compromises that can only result in the reduced ability of the system to perform as intended.

### 5.4.5 Fan Reliability and Maintenance

Air movers in nuclear air cleaning facilities must provide trouble-free reliable service, often for long periods of time and with a minimum of maintenance. Years of successful operation have proven that

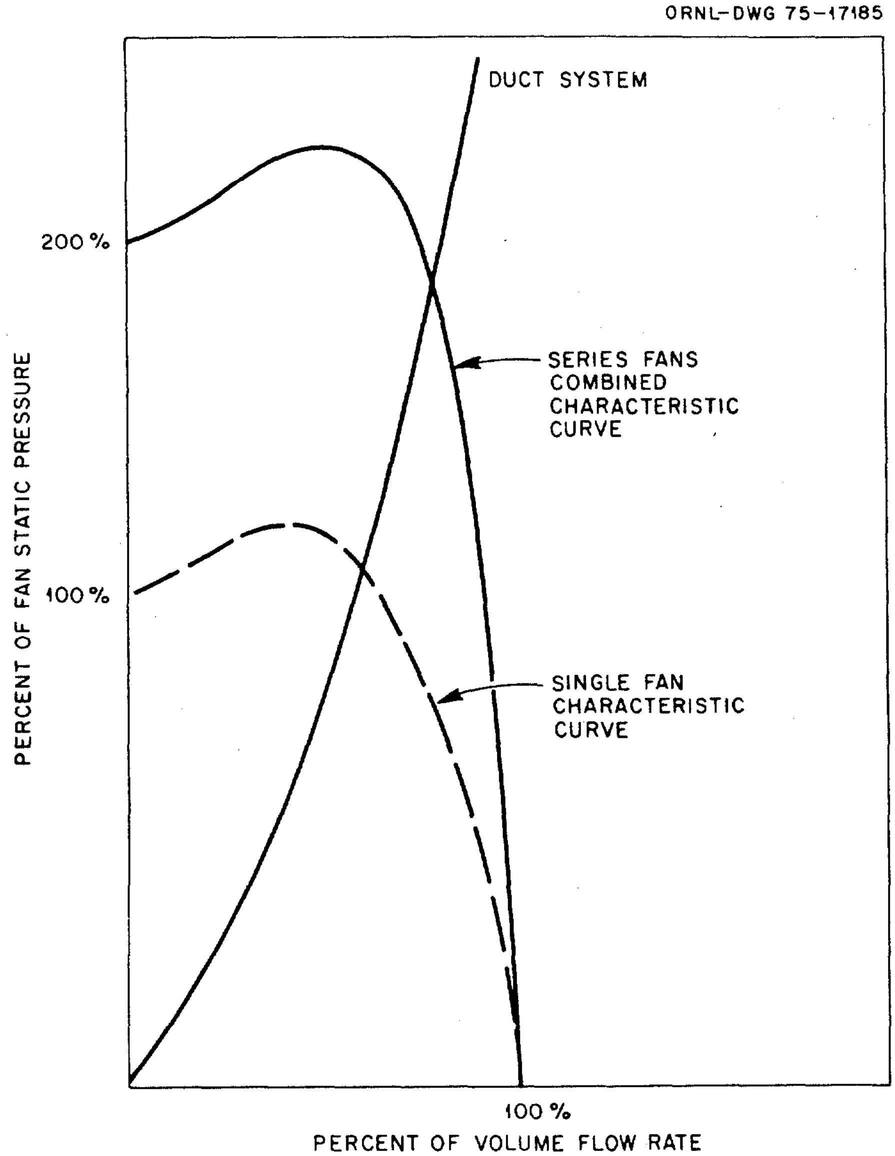



Fig. 5.9. Typical characteristic curve of two fans operating in series. From the AMCA *Fan Application Manual.*

carefully chosen centrifugal fans are capable of providing such service. In recent years, in-line-centrifugal and vane-axial fans have also been used successfully in an increasing number of applications. These fans require less volume and space for a given volume-pressure duty, and their installed weight is generally less than other conventional air-moving devices. In addition, because of the straight-through design, they can withstand shock waves in the duct system better than the conventional centrifugal fan, and they can tolerate high humidities and temperatures without failure or loss of efficiency. This ability to endure severe duty has been proven in tests designed specifically to simulate all conditions, including seismic shaking, which are likely to be encountered in a nuclear reactor containment during and after a DBA. With an integral semiopen motor of proper design that incorporates radiation-resistant windings and insulation, an independent cooling water system is not required, nor is a sealed-off environment, for the motor. The design requires no heavy complicated support structure to satisfy seismic or other loadings postulated for the most stringent service in a nuclear facility and is simple to

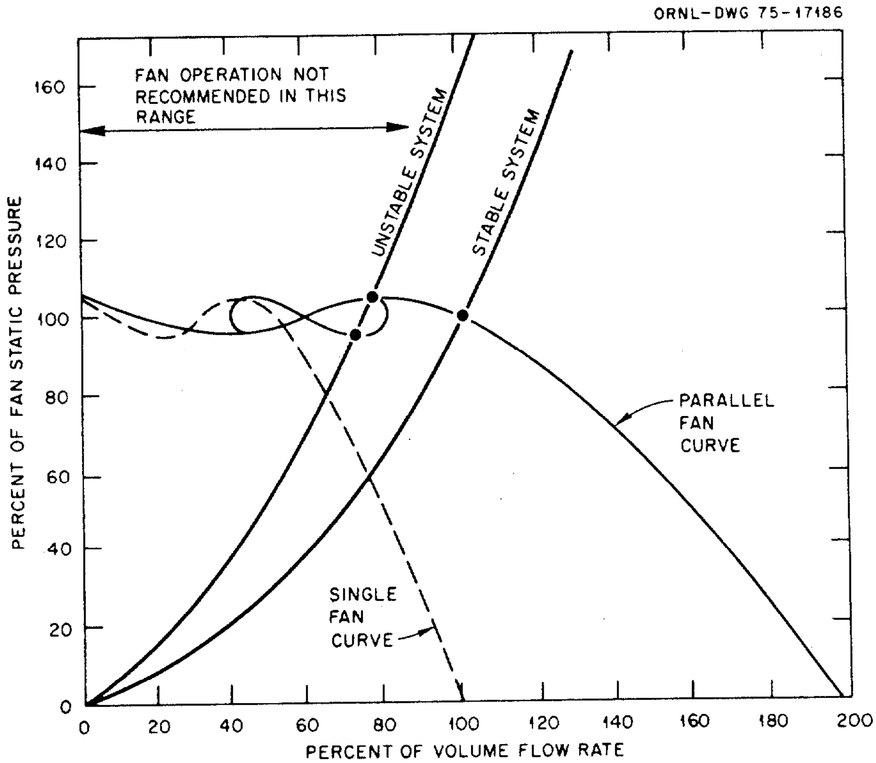



**Fig. 5.10. Typical characteristic curve of two fans operating in parallel.** From the AMCA *Fan Application Manual*.

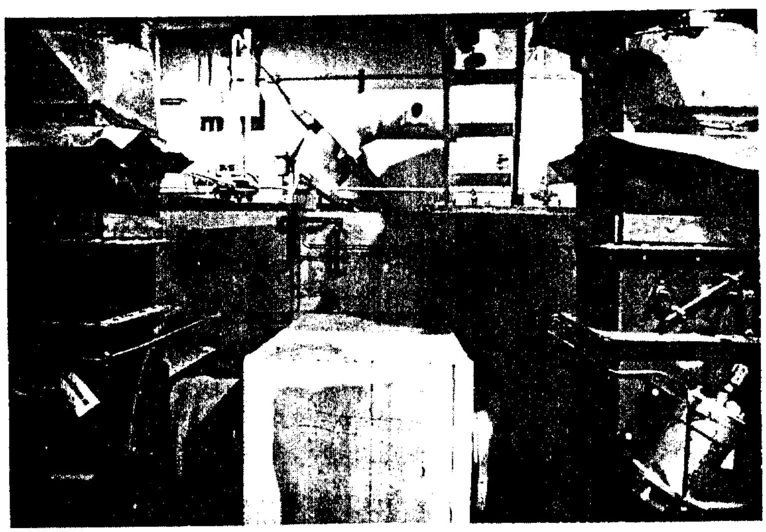


**Fig. 5.11. Parallel fans with common inlet box.**

operate and maintain. Additional information on fan types and their application is given in refs. 26 through 29.

Fans for nuclear power plant postaccident cleanup systems present special problems. If the fan and motor are located inside the primary containment, they must be able to operate continuously for long periods of time at both normal containment conditions (usually negative pressure with respect to atmosphere and temperatures of 100 to 120° F) and following a DBA or SSE. The DBA service environment includes pressure as high as 50 psig, temperature as high as 280° F, air density as much as three times normal, and exposure to heavy-rain conditions if containment sprays are provided. Water cooling may be required for the motor(s), with an alternate water supply and an alternate power supply in the event of failure of the normal supply. Alternate-redundant air cleaning units, fans, motors, or combinations of these may be required to ensure high probability of continuous function in the event of a maximum incident (i.e., DBA or SSE). Because motors and fans to meet these conditions require special design, the plant owner must obtain documented proof, based on reliable model or prototype testing, of their ability to perform under such conditions, including calculations and test data pertaining to all components. Acceptance tests are essential to verify that the equipment, as furnished, is capable of performing as promised by the qualification test data. In addition, regular and routine operational checks should be made in accordance with a preplanned schedule to verify the continued reliability of the system.

Dependability of operation is an important consideration in the selection of fans for nuclear applications. Even when the system is planned for part-time or intermittent operation, continuous operation may be required after the system goes into service and should be considered as the norm for design purposes. Savings in capital costs achieved through the specification of light-duty equipment are offset quickly by high maintenance costs after the system goes into service, even for a brief period. Roller bearings are preferable to journal bearings in fans and motors because of their superior operating characteristics, lower maintenance, and greater availability of replacements. Direct drive is generally more reliable than V-belt drive, although it is not as flexible for the adjustable flow rates often demanded by changing system requirements in laboratory and experimental facility applications. When V-belt drive is specified, at least 25% extra belt capacity should be required over that required to carry the starting load of the motor; this extra capacity gives better wear characteristics and ensures continued operation in the event of partial belt failure. AMCA drive arrangement 4 or 8 is recommended.[29]

### 5.4.6 Fan Installation

Proper mounting of the fan will minimize noise and vibration and reduce maintenance costs. Noise is objectionable in supply and exhaust systems and is often difficult and costly to eliminate after the system goes into service. Excessive noise in exhaust and air cleanup systems is often accompanied by vibration and pulsation that may be harmful to filters, adsorbers, and other components. Flutter or "reeding" of HEPA filter separators, for example, is a common cause of filter failure, and vibration of activated-carbon-filled adsorbers can cause settling and crushing of the granules and, eventually, carbon loss that can cause bypassing of contaminated air.

When practicable, mounting of the fan and motor on a common base designed for isolation of vibration is recommended. Figure 5.12 shows a typical base for large fans. The fan and motor are mounted on a concrete pad that acts as an inertial mat to limit the amplitude of vibration and to dissipate vibrational energy. The pad is mounted on spring isolators, which will provide a high degree (99% or more) of vibrational damping. For some systems, positive amplitude limiters may be required to restrain the base from excessive movement under extreme conditions (such as the accelerations imposed by an SSE or DBA). In some cases, fans may be hard-mounted, as shown in Fig. 5.13. Careful balancing of the fan shaft and impeller to minimize vibrations that cannot be isolated via installation design is particularly important in this latter design.

Floors and walls adjacent to the fan and filter housing should be designed for minimum resonance. This can be done for simple structures by first determining floor deflection through the use of standard beam formulas[30] and then by determining the vibrational frequency of the structure from the equation[31]

$$f = \frac{187.7}{y^{1/2}} \tag{5.1}$$

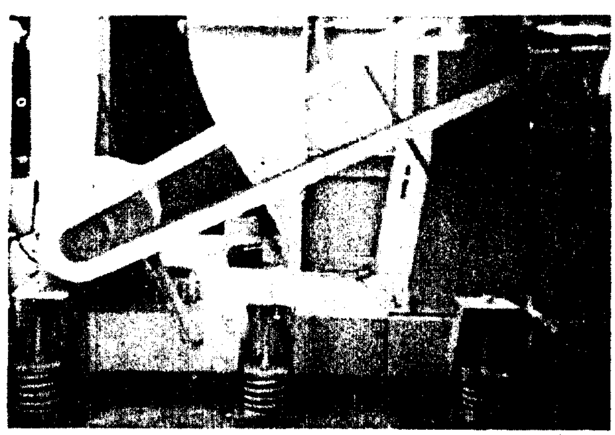


Fig. 5.12. Inertial mounting for fan and motor in building exhaust system of a transuranium laboratory facility.

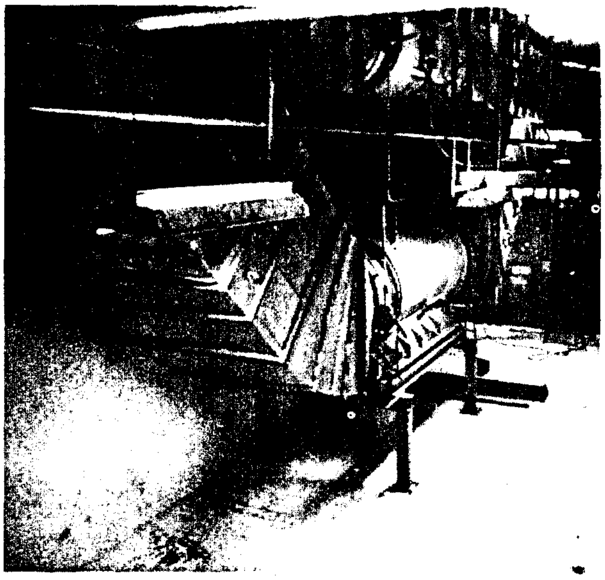


Fig. 5.13. Hard-mounted axial-centrifugal fan in reactor ESF exhaust system.

where

$f$ = frequency of vibration of the structure, Hz;

$y$ = deflection of supporting beams or floor under normal load, as determined from beam formulas,[30] in.

For minimum vibration, the speed of the motor and fan should be at least 25% less than the vibration frequency of the structure. Walls and plenums can be checked by a similar method, by using the deflection due to static pressure in the plenum for finding the vibration frequency. Where practicable, the fan should be mounted directly over a column to obtain maximum rigidity. A fan that is to develop a static pressure of 4 in.wg or more should be tested at the factory and checked for vibrations at the bearings and fan housing extremities.[31]

Vibration created by fans, motors, and drives can be isolated through the use of flexible connections between the fan and ductwork. Where such connections are used, a frequent problem has been tearing and pulling-out of the fabric (from which the flexible connection is made) at the connector clamp. The flexible connection design shown in Fig. 5.14 can overcome these problems. The fabric shown consists of two layers of 30-oz neoprene-impregnated fiberglass cloth, lapped so that the ends are displaced from one another, and glued.

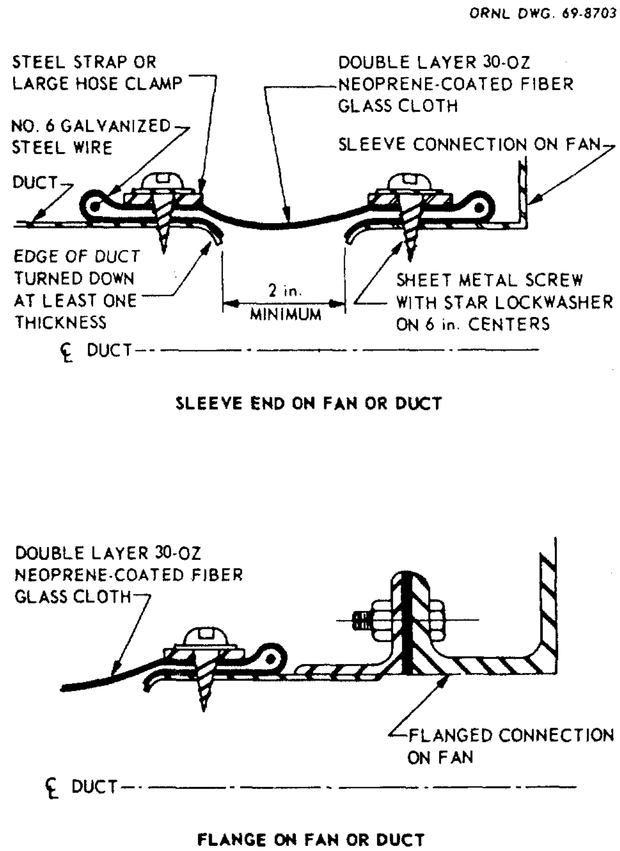



Fig. 5.14. Recommended design for flexible connections between fan and ductwork.

### 5.4.7 Location of Fan

Fan location has a direct bearing on ventilation and air cleaning system performance. Fans in contaminated exhaust systems are normally installed downstream of the filters and as close to the stack as possible. This places the fan in the most favorable location with respect to duct cleanness and the protection of personnel from contamination during maintenance. This position also provides negative pressure in as much of the duct system as possible in order to minimize outleakage of contamination to occupied areas of the building. Locating a fan within the filter housing reduces duct transmission of noise and vibration, eliminates shaft leakage problems and some ducting, and makes a flexible connection between fan and ductwork unnecessary; however, this may be a poor location from the standpoints of access and fan-entrant pressure losses. The location of a fan in a potentially contaminated area can also cause problems. The flexible connections between fan and ductwork and fan and shaft penetrations are obvious leakage paths which could permit contaminated air from the room to bypass the air cleaning facilities if the fan is located on the suction side of those facilities.

The location of a fan outside a building is not recommended. Even with a shed to protect it from the elements, there is a tendency for the fans to receive less attention (i.e., inspection, maintenance, and timely service). When fans are located outside the building, service may be inhibited during inclement weather and condensation problems often develop. Except for the lack of service during inclement weather, the same problems exist for fans installed inside but in unheated off-corners of the building. Reasonable access for maintenance and service is imperative, and fans installed above floor level must have sufficient clear space around and below for personnel to get to them with the aid of ladders and/or scaffolding.

## 5.5 AIR INTAKES AND STACKS

### 5.5.1 General

The design and location of exhaust stacks and air intakes have an important bearing on system performance. If air intakes are too close to the ground, blowing sand, dust, grass clippings, and other particulate matter may be drawn into the building, plug the supply-air filters, and/or reduce their life. Exhaust fumes from vehicles passing nearby or standing close to the building may also be drawn into the building supply-air system if the intake is too close to the ground. Intakes must be sited to protect them from snow, ice, and freezing rain during the winter months, and baffles or louvers must be provided to give protection from driving rain and to minimize the effect of wind. Although horizontal louvers are preferred by architects for aesthetic reasons, vertical louvers are more effective for removing and draining water drawn into the intake. Wind pressure can have an appreciable effect on flow rates in a low-head ventilation system and can cause pulsations that may disrupt or reverse differential pressure conditions between zones of the building.

The average wind direction and weather conditions that are likely to cause stack discharges to come close to the ground (the phenomena known as looping and fumigation) must be analyzed when establishing the location of stacks and intakes to ensure that stack effluents cannot be drawn back into the building or into an adjacent building. Intakes should be located upwind of stacks (i.e., based on prevailing wind for the site). Intakes downwind of shipping docks may be prone to drawing vehicle exhaust fumes into the building. Intakes located close to a roof or in a roof penthouse may have the same problems as those located too close to the ground.

### 5.5.2 Stacks

Low exhaust stacks should be avoided because nearby buildings and/or the unevenness of the ground may cause eddies, whorls, or stagnant air pockets (e.g., the presence of a hill having a slope steeper than 15° is sufficient to create an adjacent stagnant zone). A stack height of two and one-half times the highest point of the building or any adjacent building within 500 ft is recommended;[32] however, in no case should the stack end be less than 12 ft above the building or any adjacent building. Stacks must be structurally designed to withstand maximum predicted wind loads; they may be single-wall or double-wall. The single-wall stack is initially the least expensive design and can have riveted or, preferably, welded seams. Wall thickness may vary from a minimum of No. 16 U.S. gage for sizes up to 14 in. in diameter (or 14 in. for the longest side of rectangular stacks) to No. 10 U.S. gage or heavier for stacks over 18 in. in diameter. Number 12 U.S. gage is recommended for single-wall stacks between 14 and 18 in. in diameter (or the widest side). Stainless steel is recommended where corrosion may be a problem (type 409 or 430 where corrosive fumes are discharged only occasionally, type 304 or 316 where corrosion is a serious problem). Porcelain-lined stacks are also available; they should have two coats of enamel to avoid early failure.

Double-wall stacks have a substantially higher first cost but may be more economical in the long run when condensation is a problem. Double-wall stacks are generally prefabricated and have two distinct advantages over single-wall construction: (1) the stack does not lose as much heat as a single-wall stack; instead, heat remains in the gas and prevents excessive cooling and the resultant loss of plume rise; and (2) the relatively thin inner liner is rapidly heated to a temperature above the dew point during startup, thus minimizing condensation and hastening evaporation.[33]

The "Chinese hat," "goose neck," and similar stack-end treatments that divert discharged air downward should be avoided because of the potential for creating a personnel hazard in the event of a breach in the air cleaning system. Such treatments impose an unnecessary back pressure on the system, prevent straight-up discharge, and minimize effective stack height. In addition, they are often ineffective in preventing rain from dripping down the stack. The concentric-sleeve vertical-discharge stack end shown in Fig. 5.15 is recommended; the offset stack-end designs shown in *Industrial Ventilation* are also suitable but will create some additional pressure loss.[34]

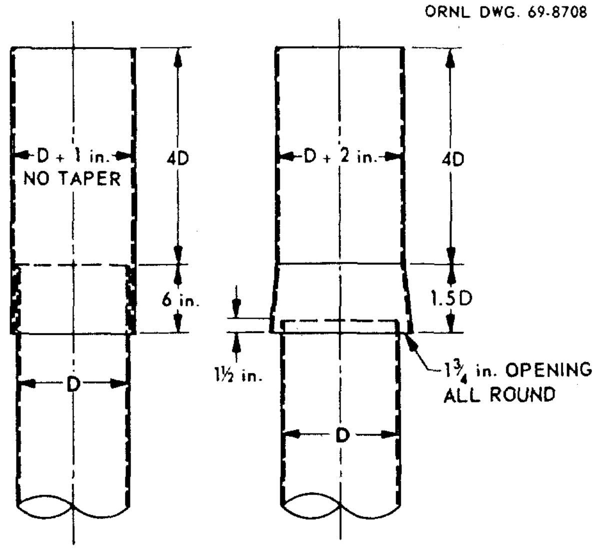



Fig. 5.15. Concentric-sleeve stack-end dimensions. Design on the right is preferred but may be more expensive.

## 5.6 VENTILATION SYSTEM CONTROL AND INSTRUMENTATION

### 5.6.1 Introduction

The parameters of major interest in nuclear ventilation systems are airflow and pressure. The usual control procedure for an exhaust system is to maintain constant airflow and monitor pressure to ensure safe operation. Control limits for safe operation are determined in the design stage, and the system is operated within those limits. Any modification of the ventilation system requires a reevaluation of the control limits and, for automatic control systems, an evaluation of the change on the control system. Control system design, instrument selection, location and installation, and instrument sensing and actuating line location and installation must consider the consequences of single-component failure; single-system failure; catastrophes such as fire, explosion, earthquake, tornado, and flooding of the contained space; ventilation system deterioration or failure; failure of power or actuating media (e.g., instrument air); and the pressure and temperature ratings of the equipment and contained spaces served by the ventilation system. Airflow control can be achieved by (1) control dampers, (2) variable inlet vanes on the fan, (3) variable speed fan, or a combination of these.

### 5.6.2 Damper Control

The throttling damper (Sect. 5.3) is the simplest, lowest first cost, highest operating cost, and most widely used method of ventilation system control. If the pressure available from the fan to compensate for dust loading of the filters is small (less than 25% of the fan static pressure at the operating point, as shown in Fig. 5.16*a*), throttling dampers may be used without an unreasonable operating cost penalty. Single-blade (e.g., butterfly) dampers should be used insofar as practicable in automatic control systems because hysteresis (the difference in linkage or blade stroke when the blade moves from the full-open to the full-closed position and when it moves from the full-closed back to the full-open position) in multiblade dampers makes it difficult, if not impossible, for the instruments to correlate blade position (i.e., damper opening) with stroke. The result, in an automatically controlled system with multiblade dampers, is "hunting" of the control system and dampers, and oscillation of airflow.

### 5.6.3 Variable Inlet Vane Control

If the differential pressure available from the fan to compensate for dust loading is 40% or more of the fan static pressure at the operating point, inlet vane control is desirable. An inlet vane control damper costs about three times more than equivalent parallel-blade or opposed-blade dampers, but, at a capacity reduction of 50% or less, it produces power savings that may average 25% as compared to the parallel-blade or opposed-blade control damper.[35] Another factor that recommends the inlet vane damper over a control damper in the duct is that it permits operation of the fan for long periods at much below the fan's maximum efficiency. Full-open inlet vane dampers cause the fan to operate at some penalty to airflow, static pressure, and horsepower (Fig. 5.16*b*). One tube-axial fan manufacturer indicates a 10% increase in brake horsepower, a 3% decrease in airflow, and a

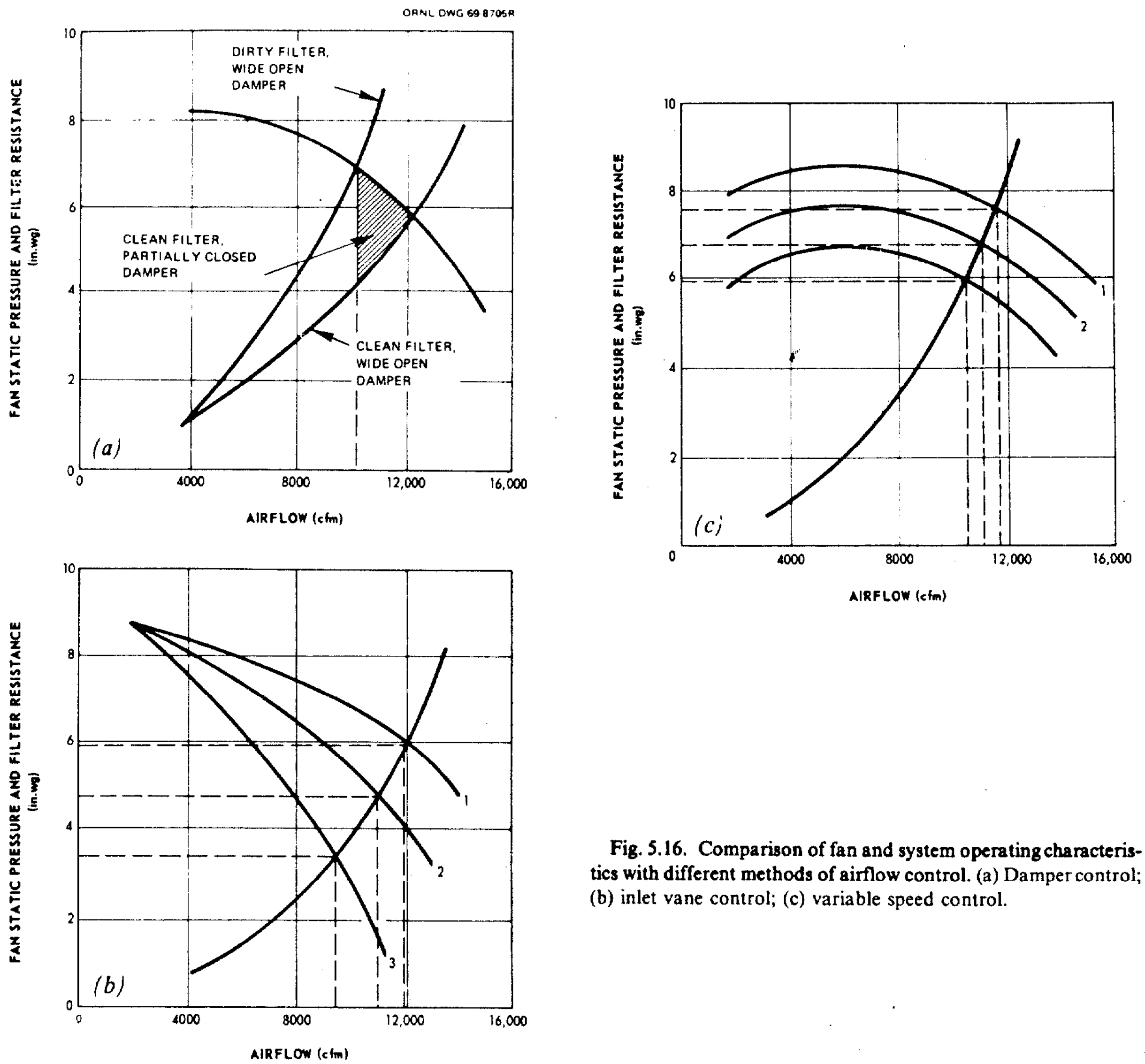



Fig. 5.16. **Comparison of fan and system operating characteristics with different methods of airflow control.** (a) Damper control; (b) inlet vane control; (c) variable speed control.

6% decrease in static pressure when the fan is operated with its inlet vane damper in the full-open position, as compared with operation without an inlet vane damper.[36] Other fan types, including centrifugals, show a similar decrease in performance when operated with an inlet vane damper in the full-open position (see Fig. 5.17).

The AMCA *Fan Application Manual* recommends the use of variable vane inlet dampers when the fan is to be operated for long periods at reduced flow.[23] The effectiveness of this damper stems from the fact that the inlet vanes generate a forced inlet vortex that rotates in the same direction as the fan impeller; similarly, any restriction of the fan inlet reduces the fan performance. Inlet vane dampers are of two types: integral or built-in, and add-on. The resistance and system effect of inlet vane dampers in the wide-open position must be considered in the original fan selection and system functional design. System effects of inlet vane dampers should be available from the fan manufacturer; if not, the system effect curves of AMCA 201[23] should be applied to account for pressure losses due to the use of these dampers.

Although variable vane inlet dampers generally provide smooth airflow control down to less than 30% of operating-point flow, there have been instances of severe vibration on large fans when the

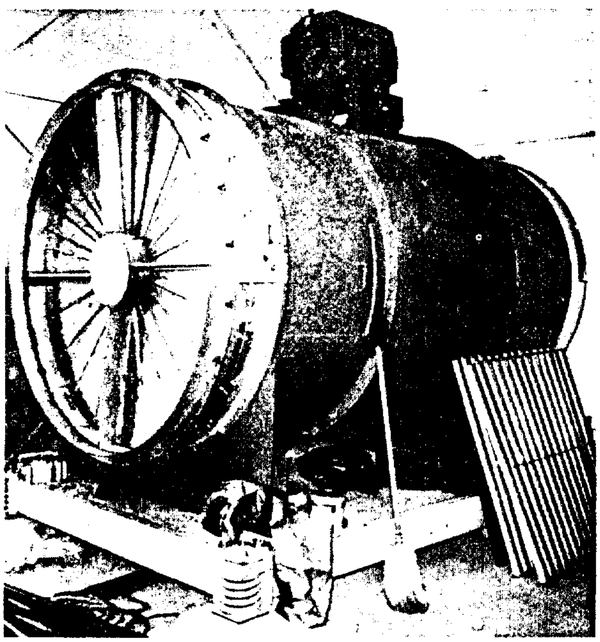


Fig. 5.17. **Vane axial fan with variable inlet vane control damper.** Damper is add-on type that could be made by other than the fan manufacturer. Damper is in full-closed position to protect fan during construction. Courtesy Mound Laboratory.

vanes were positioned between 30 and 60% opening. Because vibration is aggravated by system turbulence, consideration must be given to ways of ensuring smooth airflow patterns in the duct entering the damper and leaving the fan when inlet vane dampers are employed in high-velocity systems.

### 5.6.4 Variable Speed Control

Variable speed fans represent the highest-first-cost but lowest-operating-cost means of controlling airflow. Speed control may be achieved by variable pitch sheaves on the fan and motor, hydraulic drive, or variable speed motor. Variable-pitch-sheave drive is the least expensive but most trouble-prone method. Hydraulic drive costs less than variable speed motors, permits starting of the motor under high torque, and is generally trouble free. However, operation of the fan at less than full speed is inefficient; some hydraulic drive clutches are difficult to operate near the full-speed position; and all require an auxiliary lube oil system. Throttling dampers are required in most systems for branch line control, apart from the requirement for total system airflow control. The effect of these branch line dampers on the system must be considered in motor and fan selection. Figure 5.16*c* shows the system effect of variable speed control.

### 5.6.5 Automatic Control

High reliability of the ventilation control system is essential, because malfunction of that system during an emergency or power outage could cause malfunction or failure of the ventilation system, thus jeopardizing the safety of operating personnel and perhaps permitting a release of contamination to the environs. Automatic control of the ventilation system is desirable, if not mandatory, when rapid response is required to variations in system control parameters, malfunctions, or operational upsets in the contained spaces served by the system. To maintain the pressure differentials between various building spaces necessary for directional control of airflow, many ventilation systems require continuous fan operation, and immediate switching to an alternate fan in the event of an emergency or failure of the on-line fan or its power supply. Automatic control is also desirable because of the shortcomings of human nature. Despite the best of procedures and administrative controls, operational personnel in the spaces served by the ventilation system will, in most cases, be primarily concerned with performance of the day-to-day duties relating to the function of the facility and can be expected to pay no more than minimal attention to proper operation of the ventilation system. In an emergency, the first reaction of many will be to run rather than to stay in the area of possibly high danger to make adjustments necessary for control of a manually controlled system.

On the other hand, automatic control is expensive and has been reported to give less than satisfactory results in some nuclear facilities. Investigations have shown serious shortcomings in some areas of present-day automatic control system design and operation. Four features are essential to the reliability of an automatic control system for nuclear applications. First, a reliable automatic control system must be designed by thoroughly competent instrument engineers who have demonstrated their ability to recognize and accommodate the requirements and peculiarities of this type of system. Second, only components of known reliability can be used; the ordinary instruments and dampers used in residential and commercial heating and air-conditioning service and in many industrial applications have no place in a high-reliability nuclear automatic control system. Third, skilled and competent instrument technicians must be available to correct system anomalies. Where technicians are not available for full-time employment, instrument and control system service can sometimes be contracted but is less desirable. If the services of well-trained, competent instrument technicians are not available to the facility, the use of automatic control is questionable. Fourth, modifications to the ventilation system must be evaluated with respect to their effect on the automatic control system. Many cases of automatic control system malfunction and unreliability have been traced to changes made in the ventilation system that were never brought to the attention of the instrument department. Such changes may include adding or dropping glove boxes to or from a glove box line; replacing a glove box with a chemical fume hood; or simply dampering a glove box, cell, or building space out of a system. Any of these procedures can cause unbalances that will affect the operation of the control system. Automatic control systems are costly and reportedly are costly to maintain (although investigations of current systems suggest that high maintenance costs, in well-designed and -installed control systems, may be a myth). However, in the wake of a serious incident or catastrophe, no investigating committee will seriously consider the validity of cost as a determining factor in the design, procurement, or operation of a control system. Problems sometimes arise in automatic control systems because designers fail to recognize that dampers, measuring devices, and other restrictions in the duct are essentially orifices, and that duct entering and leaving such devices must be designed for smooth airflow upstream and downstream for proper operation of the device. Other problem areas often overlooked are hysteresis in control dampers (Sect. 5.5.3) and sizing and installation of instrument sensing and actuator-fluid lines (Sect. 5.6.7).

### 5.6.6 Central Control

Monitoring and control of all but the most simple ventilation facilities is desirable in both automatically controlled and manually controlled systems. Most changes that take place in a high-efficiency air cleaning system occur very slowly and can be monitored by a routine check of pressure, differential pressure, and airflow by operating personnel who are primarily responsible for other functions in the plant. Abnormal conditions are best signaled by an alarm which triggers when a monitored parameter rises above or falls below some predetermined set point. Central control has the advantage that such readings can be made, the effect of changes to the monitored parameters can be determined, and corrective action can be taken without a trip to the field. However, sufficient local instruments at the point of interest should also be provided to facilitate maintenance and inspection and to provide a check on the central instrumentation. Centralized control, particularly if instruments and control switches (e.g., for fans and dampers) are laid out on a graphic display panel, enables the operator to rapidly assess a situation, to determine the cause of an upset condition, to determine its interaction with other systems and its safety ramifications, and to take rapid action when necessary. The system response to corrective action can be monitored, reassessed, and modified in minimum time without entering potentially contaminated spaces of the building. Centralization of control also provides a focal point where operational information can be funnelled under normal operating conditions, for feedback purposes, and where knowledgeable personnel can be contacted in an emergency.

### 5.6.7 Instrumentation

Safe and reliable operation of a ventilation system, whether automatically or manually controlled, requires instruments to monitor critical operating parameters. As a minimum, such instrumentation includes pressure drop across each individual bank of HEPA filters (not just a single instrument to read pressure drop across the total filtration system), and airflow rates at critical points in the duct. Pressures in critical operating areas of the facility and pressure differentials between areas may also have to be monitored. Quality instruments, with accurately engraved and legible scales, rugged enough to withstand continuous operation under less than ideal conditions without loss of accuracy, and durable enough to last for the life of the installation, are essential. As noted earlier, unreliability in automatic control systems has more than once been traceable to poor choices in the selection of instruments. The principal requisite for locating instruments is accessibility. An instrument that is out of easy reach or is not easily readable will not be maintained or used. Instruments should be located at eye level or only slightly above or below. Panel mounts should be provided for fragile items and for those that require service entry from the back. Instruments that are adversely affected by vibration, particularly those with delicate electrical contacts or springs, should be installed on vibration isolators or on panels that are mounted on vibration isolators. Where stable support is not available, the panel should be mounted on its own standard. Instruments with related function should be grouped on a single panel or adjacent to one another, as indicated in Fig. 5.18, so that operators can correlate related readings, such as

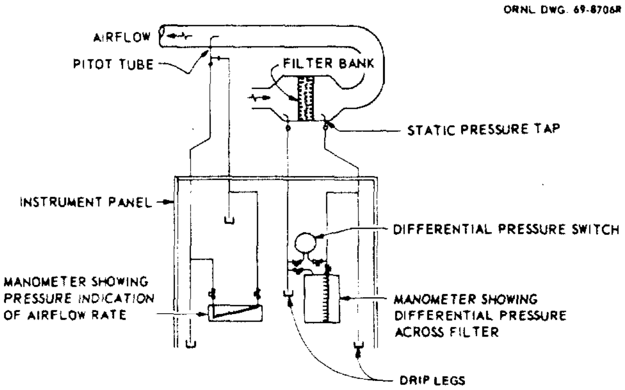



Fig. 5.18. Grouping of instruments with related function.

pressure drop across filters and airflow in the ducts, without going to several locations. Critical ventilation systems that cannot be permitted to fail or to be misunderstood (because of erroneous instrument readings) may be fitted with redundant instrumentation for certain critical parameters. Redundant instruments must be totally independent so that failure of one, from a cause either internal or external to the instrument/ventilation system, cannot affect the other.

Installation of instruments out-of-doors should be avoided when possible but not at the expense of greatly extending sensing lines that would decrease sensibility or reliability, or at the expense of inaccessibility. When located out-of-doors, instruments must be protected from the weather. Indicating fluids in manometers must be of a type that cannot freeze or boil under the temperature extremes that can occur at the site, and that will not change color if exposed to sunlight. Plastic instruments, instrument cases, and instrument cover glasses should not be used in outdoor installations. Raintight electrical cabinets, NEMA class 3, are recommended.[37]

In low-hazard areas of the building where easy access is possible, the requirement for pressure drop and airflow readings for simple, noncritical systems can often be met by providing for temporary attachment or installation of portable instruments. For pressure drop readings, a sealable length of tubing that penetrates and is welded to the duct wall is satisfactory. A simple hole in the duct, sealable by tape, may be sufficient for inserting a hand-held pitot tube. For critical systems, however, permanently installed instruments must be provided in accessible locations as close to the monitoring point as practicable, with usually a remote slave instrument in the central control room. For critical systems, the location, number, and size of instrument taps and instruments must be specified in the original design, and any changes after the system goes into operation should be recorded in the "as built" drawings.

Actuating fluid (e.g., instrument air) and sensing lines should be large enough that they cannot be plugged due to freezing of condensed water collected in them, or from contaminants that inadvertently get into the lines. A minimum tubing size of $^3/_8$ in. OD is essential for outdoor lines and is recommended for all lines, indoor or outdoor. Sensing lines must be kept as short as possible to minimize the time response to parameter changes, and they should have a minimum number of bends or flow restrictions. Sensing lines should be rigid to prevent expansion under pressure or temperature extremes that could result in false readings or multiply short-term parameter variations. Preferably, lines should be run and instruments located above the ducts to minimize condensation problems. Because such locations are often impossible, however, as a minimum, lines should be sloped to low points fitted with drip legs, and instruments should be fitted with drip legs. Figure 5.19 illustrates good installation practices for sensing lines. Where sensing lines are located in or are serving contaminated spaces or spaces in which caustic or acid fumes are present, they should be made of stainless steel, and instruments should be located far enough away from the contaminated space that migration of such contaminants to the instrument is minimized. In particularly critical applications (e.g., hot cells), a very-low-velocity purge line may be attached to the actuating fluid or sensing line; the purge flow must be very low, of course, to avoid influencing operation of the device or affecting readings.

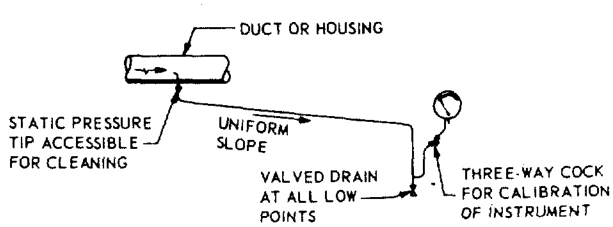



Fig. 5.19. Proper orientation of instrument sensing lines.

## REFERENCES FOR CHAP. 5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